JOURNAL OF THE AERONAUTICAL SCIENCES

VOLUME 4 NUMBER 3

JANUARY, 1937

Published by the

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VOL. 4 JANUARY, 1937 NO. 3

Editor: J. C. HUNSAKER, *Massachusetts Institute of Technology*

PUBLISHED MONTHLY BY THE INSTITUTE OF THE AERONAUTICAL SCIENCES, INC.
AT 99–129 NORTH BROADWAY, ALBANY, NEW YORK

The JOURNAL OF THE AERONAUTICAL SCIENCES is the official publication of the Institute of the Aeronautical Sciences, Inc., and is devoted to papers on experimental, theoretical, and applied science as employed in aeronautics.

Manuscripts for publication, proofs, and all correspondence should be addressed to the Editorial Secretary of the JOURNAL. Subscription price: $5.00 per year; single copies, 50c. Foreign subscription price: $6.00 per year; single copies, 60c.

Correspondence regarding subscriptions may be addressed to Publication Office, 99–129 North Broadway, Albany, N. Y., or to the Editorial Office of the JOURNAL OF THE AERONAUTICAL SCIENCES, 5431 R. C. A. Building, Rockefeller Center, New York, New York. Cable Address: INSAEROSCI.

Entered as Second Class Matter at Post Office, Albany, N. Y., October 2, 1935. Acceptance for mailing at a special rate of postage provided for in the Act of October 3, 1917, embodied in paragraph 4, section 412, P. L. & R. authorized February 17, 1934.

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JOURNAL OF THE AERONAUTICAL SCIENCES

Volume 4 JANUARY, 1937 Number 3

Speed—And Airplane Possibilities

T. P. WRIGHT, *Curtiss-Wright Corporation*

Presented at the Aeronautic Meeting of the American Association for the Advancement of Science at Atlantic City under the sponsorship of the I. Ae. S.

December 29, 1936

Introduction

The two fundamental concepts which weave themselves into all human relationships are space and time. The desire to decrease the effective size of the world by the conquest of space and the desire to increase the effective span of life by the saving of time can be found as primary motives in a very great number of human activities.

The improvement of speed of transportation, whether involving the sending of ideas and words or transporting things and persons, has been fundamental in the advancement of civilization. The evolution of the telegraph, telephone, and radio, and of the wheel, the sailboat and steamboat, the steam and electric locomotive, the automobile, the airship and airplane has been seen. It has been said that the "very pace of life depends upon the speed with which matter can be changed into energy available for transportation."

The airplane, which is the latest method of transportation of goods and persons, has already demonstrated its superiority in the matter of speed. Airplanes not only travel faster than other vehicles of transportation but also save time by their ability to take a more direct route, thus, to some extent, cutting down distances involved in the paths of roads and rail lines which often must detour around obstructing bodies of water or mountains.

In order to show the progress in this matter of speed, examine Fig. 1. For the top speed of racing airplanes and for the cruising speed of air transports, it will be noted that, particularly in the last five years, there has been an acceleration in the rate of increase in speed, progressing in the former case from just under 300 m.p.h. to just over 350 m.p.h., and in the latter case, from about 125 m.p.h. to about 200 m.p.h. The dotted lines show what the author believes to be the probable advances in speed during the next eight to ten years, advancing, at that time, to about 500 m.p.h. for the racing seaplane, 425 m.p.h. for the racing land plane, and 300 m.p.h. as the cruising speed for the air transport. Considerations which seemingly justify these predictions (and it is realized that prophesying is a dangerous procedure) are developed subsequently in this paper.

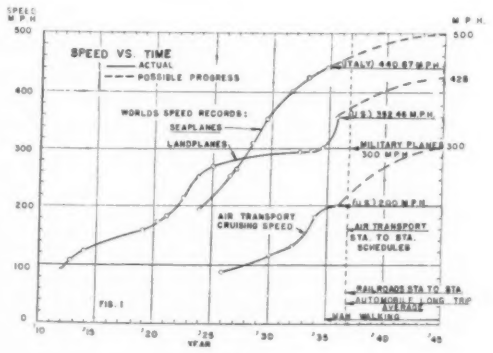

FIG. 1.

TABLE 1

TRANSPORTATION

Rail vs. Air

	Variation	*Average*
Speed Between Stations Over 200 Miles Apart.....	.30 to .40 : 1	.33 : 1
Distance Between Stations Over 200 Miles Apart....	1.05 to 1.22 : 1	1.15 : 1
Time Between Stations Over 200 Miles Apart.....	3.00 to 3.90 : 1	3.50 : 1
Fare* Between Stations Over 200 Miles Apart.....	.65 to .70 : 1	.66 : 1
Time-Cost Efficiency Factor = 1/Cost Factor × Time Factor.....		.434 : 1

*Fares cited are based on quotations for one-way trips, including Pullman fares in the case of rail travel, and not taking account of reductions for round trips, for use of scrip tickets or excursion rates, or other special considerations, such as the saving in expense for meals when travelling by air. The result of combining such factors will probably react to the advantage of air travellers, giving, in round numbers, a Time-Cost Efficiency Factor, in terms of Air vs. Rail, of 2.5 : 1.

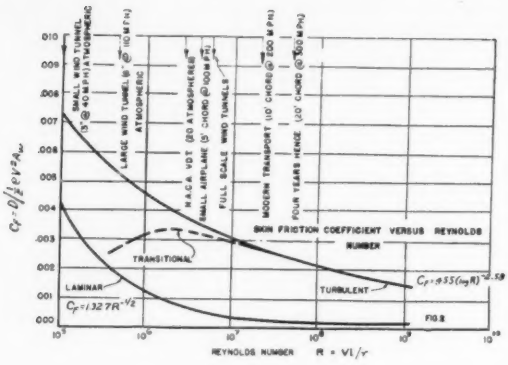
SMALL WIND TUNNEL (5' @ 40 M.P.H.) ATMOSPHERIC
LARGE WIND TUNNEL (9' @ 100 M.P.H.) ATMOSPHERIC
NACA VDT (20 ATMOSPHERES) (10' CHORD @ 100 M.P.H.)
SMALL AIRPLANE (5' CHORD @ 100 M.P.H.)
FULL SCALE WIND TUNNELS
MODERN TRANSPORT (10' CHORD @ 200 M.P.H.)
FOUR YEARS HENCE (20' CHORD @ 300 M.P.H.)
SKIN FRICTION COEFFICIENT VERSUS REYNOLDS NUMBER
TRANSITIONAL
LAMINAR
TURBULENT
FIG. 2
REYNOLDS NUMBER R = Vl/ν

FIG. 2.

In Table 1 is shown a present comparison between rail and air transportation, covering the average time saving and distance saving for air travel, with resultant improvement in speed. The lower average fare for rail travel is given and a time-cost efficiency factor worked out, roughly favorable for the air transport in the ratio 2½:1. It is such a comparison, substantiated by the rapid increase in passenger air traffic during the last six years (amounting to about 30% increase each year—and this during a major economic depression!), which leads to the conviction that continued development leading to increased speed and improved efficiency will bring about an even more rapid gain, so that in the not distant future a substantial proportion of long distance passenger traffic, as well as the long distance hauling of mail and important express, will be handled in the air.

Aerodynamic Considerations

Basic Formulae

It is desirable to consider the basic relations which govern airplane speed, in order to see directly from mathematical expressions what elements contribute fundamentally toward the desired end and their relative importance:

$V_{max.} = 550\ \eta\ P/D$, where
$V_{max.}$ = Maximum Velocity,
η = Propeller Efficiency,
P = Brake Horsepower,
D = Total Drag which is the sum of Induced Drag (D_i) and all other forms of Drag (D_p).
$D_i = (C_L^2/\pi\ AR)\ (q\ S) = C_{D_i}\ q\ S$, where
C_L = Lift Coefficient,
AR = Aspect Ratio = Span$^2/S$
$q = \rho V^2/2$, Dynamic Pressure,
S = Area of Wings,
C_{D_i} = Induced Drag Coefficient.
$D_p = D_{waste} + D_{cooling} + D_{pressure} + D_{friction}$

Waste drag is caused by eddies and turbulent flow, interference between component parts, skin friction in excess of that existing over smooth plates, and in addition, the drag of every portion of the airplane which is unnecessary in sustaining lift, in housing the load, and in stabilizing the wings, such, for example, as the drag of exposed landing gears, struts, and nacelles.

$D_{cooling}$ = Drag involved in the cooling of the powerplant, whether air or liquid.

U = Relative air velocity near any point on the surface.

Parameter for Flight at Altitude:

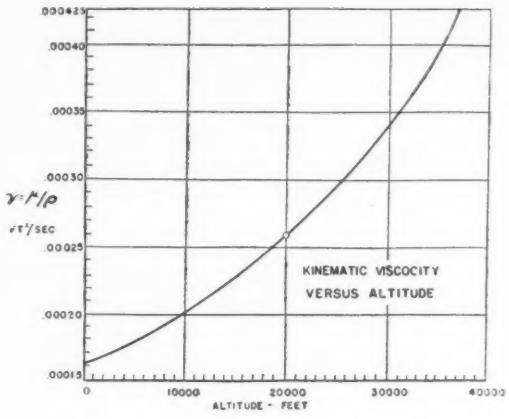

FIG. 3.

$$\Lambda = L_s L_t^{2/3} / L_p^{1/3}$$

Λ is a fundamental Parameter developed by Oswald in which

L_s = Span Loading = $W/e(kb)^2$

where W = Weight; e = Airplane Efficiency Factor; kb = Effective Span.

L_t = Trust Power Loading = $W/\eta P$,

L_p = Parasite Loading = W/f,
where f = Equivalent Parasite Area.

Combining the definitions of the loadings in the fundamental formula for Λ the following is obtained, which is of use in considering the effect of the various terms in connection with altitude performance:

$$\Lambda = W^2 f^{1/3} / e(kb)^2\ (\eta P)^{4/3}$$

$$D_{pressure} = D_{friction} \times K,$$

It is here assumed that pressure drag, due to the resultant down-stream component of the normal pressures on the surfaces, bears a constant relation to the friction drag, the factor varying for different shapes. The desirability of this concept will become apparent when the drag of typical airplanes is subsequently examined, sub-dividing the total into the various components, of which two are friction and pressure.

$D_{friction} = C_{DF} \times .5\ \rho U^2 A_{wetted}$, where

C_{DF} = Friction Drag Coefficient, varying with Reynold's Number (UL/ν) and with Roughness Coefficient (K/L) and a function of the ratio (V/A), A being the speed of sound.

ρ = Air Density, varying with Altitude.

A_{wetted} = the wetted surface (in a subsequent analysis this is assumed to include only the wetted surface of all portions of the airplane necessary to sustain weight, stabilize motion, or carry useful load. A_{wetted} in this assumption varies from 3.5 to 4.5 times the net wing area).

For good altitude performance, it is desirable to have a small value of Λ, which means a large span, large horsepower, small drag, and small weight.

Summarizing, from these basic formulae, it is found that increases in speed are obtainable through the following means:

Increase in power which, from economic considerations is undesirable; increase in propeller efficiency; decrease in drag

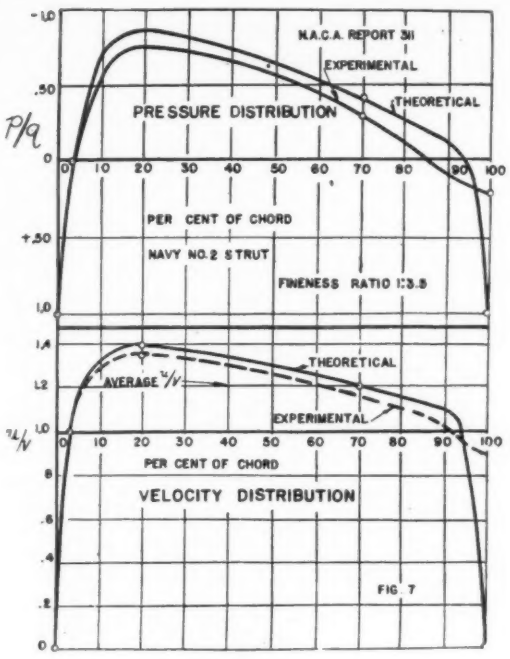

FIG. 4.

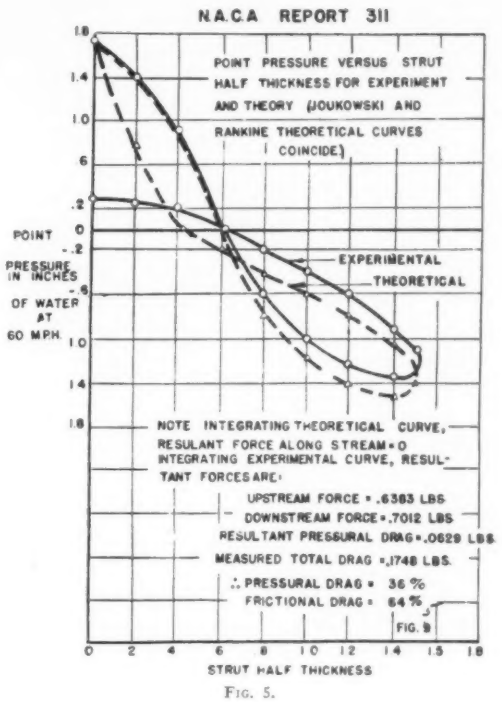
N.A.C.A. REPORT 311
POINT PRESSURE VERSUS STRUT HALF THICKNESS FOR EXPERIMENT AND THEORY (JOUKOWSKI AND RANKINE THEORETICAL CURVES COINCIDE)
POINT PRESSURE IN INCHES OF WATER AT 60 M.P.H.
EXPERIMENTAL
THEORETICAL
NOTE INTEGRATING THEORETICAL CURVE, RESULANT FORCE ALONG STREAM = 0
INTEGRATING EXPERIMENTAL CURVE, RESULTANT FORCES ARE:
UPSTREAM FORCE = .6383 LBS.
DOWNSTREAM FORCE = .7012 LBS.
RESULTANT PRESSURAL DRAG = .0629 LBS.
MEASURED TOTAL DRAG = .1748 LBS.
∴ PRESSURAL DRAG = 36 %
FRICTIONAL DRAG = 64 %
FIG. 9
STRUT HALF THICKNESS

FIG. 5.

of all kinds, including induced drag, cooling drag, friction drag, pressure drag, and all drag which is wasted in creating turbulence or which is present through the exposure of unnecessary parts; and decrease in air resistance by flight at lower density and therefore higher altitudes.

FRICTION DRAG

As the speed of airplanes increases, the importance of induced drag at low altitude becomes less, amounting in modern transports flying at ten thousand feet to only six or eight per cent of the total drag. The skin friction drag, however, mounts to a large proportion and, therefore, should now be studied in considerable detail as it is from the reduction of this item that considerable additional speed can be anticipated. Fig. 2 gives curves of skin friction coefficient as it varies with scale effect or Reynolds Number. At low Reynold's numbers the flow around the surfaces is laminar and the coefficient varies in accordance with the curve so marked. There follows a transitional stage during which the friction drag coefficient increases and then decreases finally to coincide with the curve termed "turbulent" at a value of $R = 4 \times 10^6$. Marked on the curve of Fig. 2 are the Reynold's numbers corresponding to various wind tunnels and airplanes. It will be noted that the curve for friction drag coefficient in the transitional range is applicable to most wind tunnels, thereby requiring great care in determining flow characteristics of the tunnel in order properly to establish the coefficient. Small, low speed airplanes also lie in this range. Modern transports are almost out of the transitional flow range and it is anticipated that very shortly it will be safe to assume that the size and speed of such planes will correspond to such high values of the Reynold's number, that the flow over them in the boundary layer will be entirely turbulent. There is need for some qualification to this statement, as will be subsequently explained, in that even at high values of R, the forward portion of a surface maintains its laminar flow.

The term ν represents kinematic viscosity, which is $\nu = (\mu/\rho)$. μ is the viscosity of air. The air density, ρ, decreases with altitude much more rapidly than does the viscosity μ so that ν increases with altitude as indicated in Fig. 3. As flight occurs at higher altitudes, the Reynold's Number (VL/ν), will be less by virtue of this effect.

It has been the practice in the past to use the term profile drag to combine the effects of friction and pressure. In the present analysis, it is desirable to separate the frictional and pressural drags so as to make possible the determination of total friction and total pressure drags for the whole airplane. In order to determine whether or not justification for the method exists with reasonable quantitative checks, a study was made of data for airfoils, strut sections, and three-dimensional streamline sections. In each case, the wetted area was found, it being the surface involved in determining skin friction. Then pressure distributions were studied, giving the resultant velocities adjacent to the surface. This surface velocity is then used to determine friction drag which will be greater than the drag when using the profile drag method by the ratio of $(U/V)^2$. In Fig. 4 is shown the basic pressure and velocity distribution curves for a strut section. Similar data applying to airfoils and three-dimensional shapes were also analyzed.

Friction drag coefficient was then determined but as the tests were conducted at Reynold's numbers in the transitional range, wherein some doubt existed as to tunnel flow conditions, an average value of .003 was used. Having determined the friction drag, it was then necessary to determine the proportion of friction and pressure drag. This was accomplished by plotting the pressures around the surface against the thickness and finding the algebraic sum of the up and down stream pressures and suctions, the resultant down stream force being pressural drag (Fig. 5). Then, dividing the friction drag coefficient by the proportion of friction drag to total drag, the total drag coefficient is obtained. The percentage of error when using this method is small for the airfoil and the Class "C" dirigible shape although somewhat larger for the Navy No. 2 strut. The agreement, however, is believed to be sufficiently close throughout to warrant tentative adoption for this

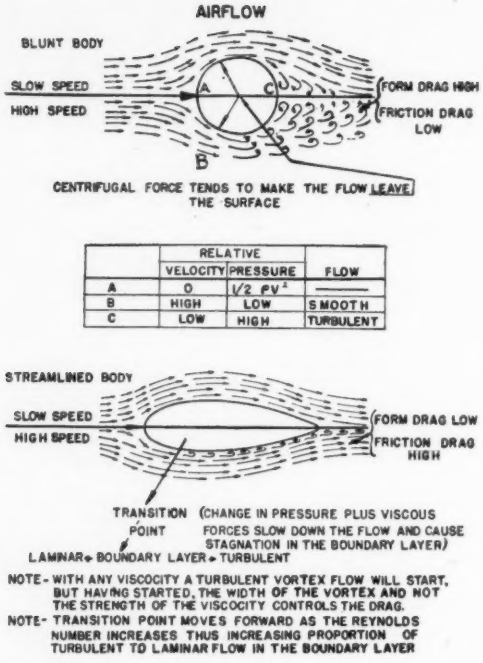
AIRFLOW
BLUNT BODY
SLOW SPEED
HIGH SPEED
A
C
B
FORM DRAG HIGH
FRICTION DRAG LOW
CENTRIFUGAL FORCE TENDS TO MAKE THE FLOW LEAVE THE SURFACE
RELATIVE
VELOCITY PRESSURE FLOW
A 0 1/2 ρV² ——
B HIGH LOW SMOOTH
C LOW HIGH TURBULENT
STREAMLINED BODY
SLOW SPEED
HIGH SPEED
FORM DRAG LOW
FRICTION DRAG HIGH
TRANSITION POINT
(CHANGE IN PRESSURE PLUS VISCOUS FORCES SLOW DOWN THE FLOW AND CAUSE STAGNATION IN THE BOUNDARY LAYER)
LAMINAR ← BOUNDARY LAYER → TURBULENT
NOTE - WITH ANY VISCOCITY A TURBULENT VORTEX FLOW WILL START, BUT HAVING STARTED, THE WIDTH OF THE VORTEX AND NOT THE STRENGTH OF THE VISCOCITY CONTROLS THE DRAG.
NOTE - TRANSITION POINT MOVES FORWARD AS THE REYNOLDS NUMBER INCREASES THUS INCREASING PROPORTION OF TURBULENT TO LAMINAR FLOW IN THE BOUNDARY LAYER

FIG. 6.

analysis of the method for use in studying the component parts of the drag of the airplane. Recently developed airfoil sections indicate the need for decreasing the proportion of pressural drag to total drag from the figures herein used in order to reconcile figures for profile drag obtained in high density or full scale tunnels with corresponding figures derived by this method. However, the ratios used here are believed satisfactorily to fit the cases of airplanes subsequently analyzed in detail.

AIRFLOW

An attempt has been made to show the airflow round a body pictorially in Fig. 6. In the upper part, the flow is shown at both low and high speed round a blunt shaped body. As the flow proceeds around the body, centrifugal force tends to cause the air to leave the surface. At low speed, this tendency is not sufficient to cause a breakdown. However, at high speed, the air separates from the surface, creating eddies and turbulence. It will be seen that at point A the velocity is zero and the pressure is equal to $.5\rho V^2$. At point B, the velocity is at its highest and the pressure at its lowest, with the flow still smooth, though commencing to break away. At point C the velocity is again reduced and the pressure raised with turbulent flow indicated, particularly for the high speed condition. Over such a blunt body at high speed, the pressural drag due to flow separation is relatively high whereas the friction drag is relatively low.

Consider a streamline body, such as shown in the lower part of Fig. 6. Here, both at low speed and at high speed it will be seen that the flow lines generally conform to the shape of the body, except for a very thin layer aft of a certain point known as the transition point, where the viscous forces slow down the flow and cause some turbulence. In the case of the streamline body, the pressural drag is relatively low as there is no eddying or general turbulence, whereas the friction drag is relatively high. In developing the classical theory of streamline flow, air is considered non-viscous. The direct drag effect of viscosity is small but the indirect effect is large, as with

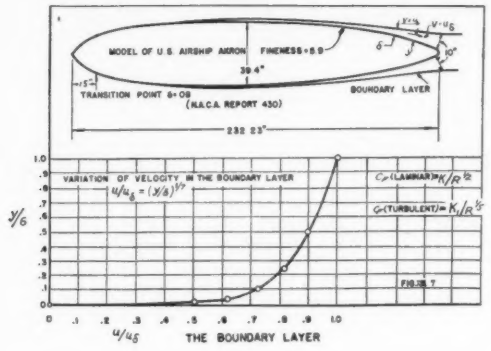

FIG. 7.

viscosity separation and turbulence may start. Having started however, it is the volume of turbulence and not the magnitude of the coefficient of viscosity which controls the drag. It is also interesting to note that a streamline body in a perfect non-viscous fluid (an assumption made in developing the theory) possesses neither friction drag nor pressural drag, a result never realized under actual conditions. Shape refinement is gradually decreasing the proportion of pressural drag. Another point of interest is the fact that the transition point in the boundary layer between laminar and turbulent flow moves forward with increasing Reynold's Number, thus increasing the proportion of turbulent versus laminar flow in the boundary layer. At present, for all practical purposes, at large values of Reynold's Number, it may be assumed that the turbulent drag coefficient may be applied throughout. However, recent research work, particularly that being performed by the staff at Cambridge University, points to the possibility of obtaining important reductions in drag through accomplishing a rearward displacement of the transition point. Practical methods of doing this are yet to be discovered, but perfectly smooth surface conditions certainly appear to be one essential factor.

BOUNDARY LAYER

In Fig. 7 is shown the outline of the U. S. Airship "Akron" which was tested in the National Advisory Committee for Aeronautics variable density tunnel with a view to determining the exact extent of the boundary layer. The outer edge of the boundary layer, defined as the closest streamline with normal velocity of flow, is shown in this drawing. In this model, 232 inches long, the thickness of the boundary layer δ is only .08 of an inch at the transition point, which is 15 inches aft of the nose, but acquires a width of 10 inches at the tail. On Fig. 7, at the bottom, is also shown a curve indicating the variation of velocity within the boundary layer. The formula which approximately obtains for the whole length of the boundary layer (altho the exponent varies slightly at different points) is $U/U_\delta = (Y/\delta)^{1/7}$. The velocity decreases as the surface is approached, reaching zero at the surface. The formula for drag coefficient (C_F) in the boundary layer is also given, both for laminar and turbulent flow.

Von Kármán has very beautifully expounded the theory of turbulence with its relation to skin friction. In laminar flow, the interaction between adjacent fluid layers consists of so-called molecular friction giving a very low shearing stress or unit friction; in turbulent flow, there is an additional interaction due to the momentum transfer from layer to layer incident to velocity fluctuations. In his discussion, he shows that next to the surface there exists a boundary sub-layer which continues laminar even though the flow directly above it is turbulent.

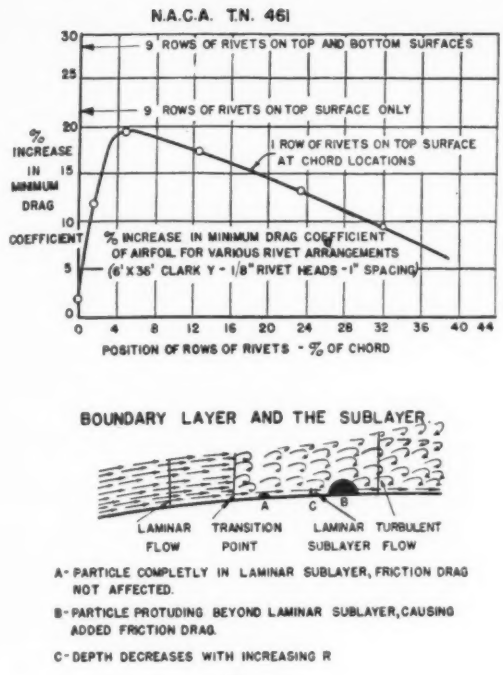
N.A.C.A. T.N. 461
9 ROWS OF RIVETS ON TOP AND BOTTOM SURFACES
9 ROWS OF RIVETS ON TOP SURFACE ONLY
1 ROW OF RIVETS ON TOP SURFACE AT CHORD LOCATIONS
% INCREASE IN MINIMUM DRAG COEFFICIENT
% INCREASE IN MINIMUM DRAG COEFFICIENT OF AIRFOIL FOR VARIOUS RIVET ARRANGEMENTS
(6' X 36' CLARK Y - 1/8" RIVET HEADS - 1" SPACING)
POSITION OF ROWS OF RIVETS - % OF CHORD
BOUNDARY LAYER AND THE SUBLAYER.
LAMINAR FLOW
TRANSITION POINT
LAMINAR SUBLAYER
TURBULENT FLOW
A- PARTICLE COMPLETLY IN LAMINAR SUBLAYER, FRICTION DRAG NOT AFFECTED.
B- PARTICLE PROTUDING BEYOND LAMINAR SUBLAYER, CAUSING ADDED FRICTION DRAG.
C- DEPTH DECREASES WITH INCREASING R

FIG. 8.

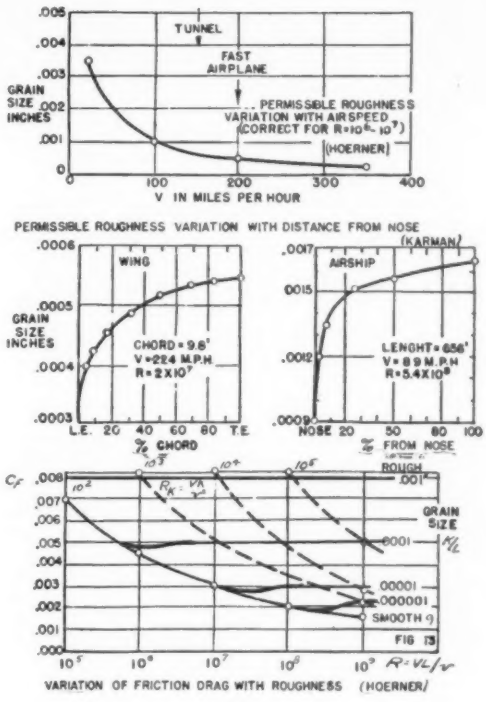

FIG. 9.

The author has attempted to show this flow condition in Fig. 8 (lower drawing), and has also shown two surface imperfections, *A* and *B*, one of which is completely immersed in the boundary sub-layer and the other of which protrudes through it into the turbulent portion of the boundary layer. This conception is necessary to understand the subsequent discussion of roughness of surface as it affects drag.

SURFACE ROUGHNESS

In Fig. 9 there are four curves shown which depict the effect of roughness. In the lower curve will be recognized the normal curve for variation of drag coefficient with Reynold's Number for a smooth plate. Branching off from this are others which indicate the friction drag coefficient applying to surfaces of differing roughnesses as measured by K(grain size)$/L$(length of body).

It will be seen that for each of these, at a given Reynold's Number, there is a slight drop and then an increase from which point on the coefficient is independent of Reynold's Number, the drag thus following directly the V^2 rule. Shown on this same chart, in dotted lines, are curves indicating the Reynold's Number of the grain itself and from this it can be seen that when such Reynold's Number is equal to 10^2 the line coincides with that for smooth surfaces, which defines the term "permissible roughness" or that limit of roughness below which no further decrease in drag will result. It develops from these considerations that within fairly wide limits the "permissible roughness" depends only on speed and grain size rather than on length of the surface on which the grains exist. At the top of Fig. 9 is a curve showing "permissible roughness" as it varies with airspeed, the plot representing grain size *vs.* m.p.h. It is seen from this curve that, in modern airplanes $R =$ about 10^7, the limit of "permissible roughness" is a grain of .0005 in. diameter. For a grain smaller than this size, the surface may be considered perfectly smooth aerodynamically. The higher the speed the smaller must be the grain in order that perfect smoothness may exist. At low speeds, on the contrary, say at 50 m.p.h., even though the grain size is .002 of an inch the surface will react as though perfectly smooth. Of course, when considering a wing at stalling speed, cognizance must be taken of the increased local velocity of 200–400% of the normal stream velocity so that in a stall of, say 60 m.p.h., the limiting grain size for the top surface forward on the chord would still be about .0005 in., as the actual velocity over this part of the surface will be determining rather than the stream velocity or airspeed of the airplane. It is brought out by Von Kármán that this "permissible roughness" curve defines a grain size which will lie entirely within the boundary sub-layer wherein the flow continues to be laminar and it is only when the particle protrudes outside of this sub-layer that increased drag due to roughness exists.

It is thus seen that the friction drag coefficient depends on grain size. In addition, it depends on the position of the grain or roughness along the surface of the body. In the middle of Fig. 9 are curves showing the "permissible roughness" as it varies with distance from the leading edge of a wing, or from the nose of an airship. As would be expected, in order that the surface of the wing, or airship, may be perfectly smooth aerodynamically, it is necessary that the grain be smaller in size nearer the leading edge or nose than at a position further aft. This is due particularly to the variation in thickness of the boundary layer, augmented by the increased velocity over the surface.

There are two other factors involved in the matter of surface roughness as it relates to skin friction, *i.e.*, altitude and density of grains. At high altitude, the Reynold's Number is smaller and therefore a larger grain size is permissible before the surface behaves as a rough surface rather than as a smooth one. Data on the effect of density, that is spacing, of grains are at present lacking and there is a great need of additional research in this field.

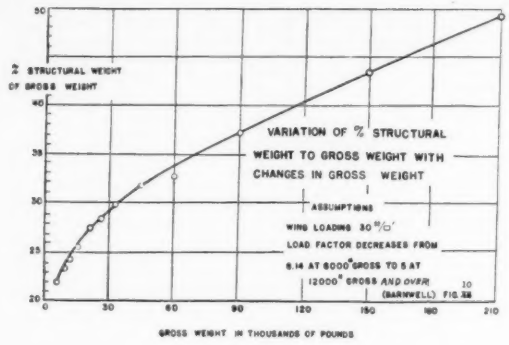
% STRUCTURAL WEIGHT OF GROSS WEIGHT
VARIATION OF % STRUCTURAL WEIGHT TO GROSS WEIGHT WITH CHANGES IN GROSS WEIGHT
ASSUMPTIONS
WING LOADING 30 #/SQ'
LOAD FACTOR DECREASES FROM 9.14 AT 6000# GROSS TO 5 AT 12000# GROSS AND OVER
(BARNWELL) FIG. 38
GROSS WEIGHT IN THOUSANDS OF POUNDS

FIG. 10.

PROTUBERANCES

The effect of protuberances on drag is two-fold. First any protuberance may be considered as, in effect, a roughness or grain which tends to create a turbulence behind it and change the skin friction characteristics of the surface. Secondly, the protuberance can be considered as a separate body having its own friction and pressure drags. In either case, the drag variation caused by protuberances will, in general, be affected by the local velocities. These will differ from that of the normal stream depending on the position of the protuberance. Tests conducted by the National Advisory Committee for Aeronautics have shown that, in general, the drag of the protuberance may be determined by considering its area and the dynamic pressure corresponding to the actual surface velocity at the point at which the protuberance exists. On a wing in high speed attitude, this factor of increase was found to amount to well over 2 when the protuberance was located at from 5–30% of the chord and the height of the protuberance was of the order of .005 to .01 times the chord. For tests which were conducted on a Clark "Y" airfoil, 6 ft.x36ft., using rows of rivet heads corresponding to 1/8 in. rivets spaced one inch apart, in different combinations of rows, the data are shown in Fig. 8, upper drawing, where the position of a row of rivets is plotted against per cent increase in minimum drag coefficient. It will be noted that nine rows of rivets on the top and bottom of the surface increased the minimum drag coefficient by the very substantial amount of 28%. This is indeed important when considering the preponderance of friction drag to other types which exist in modern airplanes and the fact that rivet spacing such as was used in the tests, in relation to the dimensions of the wing, is well within the order of such spacing in actual practice. This figure shows, in addition, the greater effect of rivets when located on the top surface than on the bottom, and also the greater increase in drag incident to a forward location of the rivets. It appears that aft of 50% of the chord there is little effect in protuberances such as is represented by the row of rivets under test. There is need for further study of this point however, before conclusions are definitely drawn.

The lapping of the metal sheets used in constructing wings causes an irregularity amounting to a protuberance. One investigation shows that such a lap, critically located, will cause an increase in friction drag of the order of thirteen per cent.

Summing up this study of skin friction, it is evident that it is important to provide a smooth surface so that the coefficient of drag may be permitted to follow the normal curve for turbulent friction for a smooth surface and furthermore, that protuberances, even of very small dimensions, which have the two-fold effect of disturbing the whole flow over the surface, and causing drag due to their own projected area, must be eliminated.

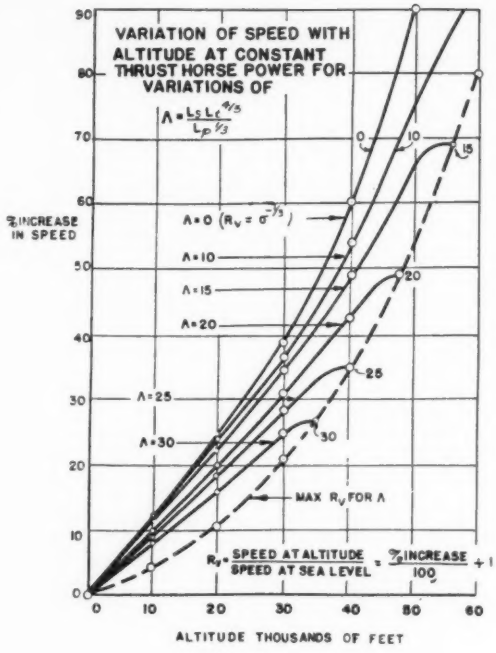
VARIATION OF SPEED WITH ALTITUDE AT CONSTANT THRUST HORSE POWER FOR VARIATIONS OF
$\Lambda = \frac{L_s L_c^{4/3}}{L_p^{1/3}}$
% INCREASE IN SPEED
A=0 ($R_v = \sigma^{-1/3}$)
A=10
A=15
A=20
A=25
A=30
MAX R_v FOR Λ
R_v = SPEED AT ALTITUDE / SPEED AT SEA LEVEL = % INCREASE / 100 + 1
ALTITUDE THOUSANDS OF FEET

FIG. 11.

Engineering Considerations

It now seems desirable to consider some practical engineering considerations affecting the speed of airplanes. First, consider size. As size increases, it is more readily possible to approach the ideal of the flying wing. Thus nacelles, landing gear, and even the fuselage may be proportionately more fully enclosed within the contour of the wing itself than can maintain when the airplane is smaller. There is less waste drag, in terms of the definition previously given, to be overcome by thrust horsepower.

In addition, with increasing size, the Reynold's Number is increased so that a lower value of friction drag coefficient will maintain. Also, there are certain auxiliary advantages of size in connection with weight, up to a definite limit for any given material used for construction. For instance, the proportion of weight necessary for controls, for the crew, for radio, and for many other items of this kind, becomes smaller as size increases. Also, when working with larger sizes and consequently greater thicknesses of material, it is possible to design more economically from the standpoint of stiffness and resultant freedom from failure through crinkling, freedom from minimum sizes, etc. On the other hand, these advantages will, at some limit, presumably be counteracted by the action of the so-called square-cube rule. This rule is based on the fact that structures of different sizes but similar throughout (and using the same materials) will be subjected to the same unit stresses if they be subjected to the same unit loadings. It is apparent from this that if wings of different sizes are constructed from the same drawings but using different scales, the weight of such wings will vary as the cube of any linear dimension, whereas the stress load which they can sustain will vary as the square of the same dimension. Barnwell has drawn up a structural weight equation by the use of which the weight of the component parts of any airplane, making up its structure and powerplant, may be determined. In Fig. 10 is shown the variation of the per cent of structural to gross weight against gross weight. The curve is based on a wing loading of 30 lbs. per sq. ft. and a slightly decreasing load factor as size increases. It is

obvious that at some point along this curve (or any curve of similar derivation but which assumes other loading, load factors, or other weight formulae), or perhaps along this curve extended, a gross weight would be reached such that the entire payload would be eliminated due to increased structural weight. For example, present day airplanes, with useful ranges of operation, carrying payloads of about 18% of their gross weight would, according to this curve, be incapable of carrying any payload for such range if increased to a gross weight of about 175,000 lbs. However, the particular formula of weight on which this curve is based assumes an increasing fuselage weight as size increases, proportionally to wing variation. This condition will not perhaps exist and, in fact, may show a slight reversal in trend, thus extending the economical gross weight limit. With improvements in material and technique constantly being made, and with a yet imperfect knowledge of all factors affecting the economics of the airplane, it would be indeed rash to predict such size limit. Some recent articles have speculated (with, the author believes, erroneous conclusions) on the possibility of airplanes using powerplants of 200,000 hp. and gross weights of 3,000,000 lbs., without allowing for the square-cube effect on wing structural weight. The author's own judgment would be to place the limit in size reasonably to be expected within the next ten years at 250,000 lbs., perhaps a little lower for landplanes.

The present form and arrangement of the airplane appears so well adapted to the performance of the functions for which it is designed, that it seems likely to continue. Improvements of the last five years have stepped up its efficiency tremendously. Such items as wing flaps for permitting higher wing loadings; constant speed propellers which improve takeoff and operating efficiencies; retractable landing gears for reducing wasted drag; NACA cowls for reducing cooling drag; and moderate supercharging of the engines which permit speed increases due to flying at altitude; have made possible truly astounding advances. Here there is evolution brought about by a series of minor revolutions of varying importance.

Effect of Attitude

The effect of flying at increased altitudes may now be studied. In Fig. 11 the author has shown curves which give the increase in speed when flying at altitude (as against flight at sea level) *vs.* altitude with Λ (previously defined) as parameter. In these curves account is taken of the effect of decreased density on parasite drag and of increased lift coefficient on induced drag. For complete accuracy, however, an additional reduction is necessary due to reduced Reynold's Number inherent in high altitude flight due to the reduction of ν with altitude increase. Modern air transports have values of Λ of the order of twenty and it is thus seen that when flying at 10,000 feet as against flight at sea level, an increase of 9% in speed is obtained. To obtain such improvement by decreasing drag when flying at sea level would require a drag reduction of about 30%. Now if this airplane could be flown at 35,000 feet, the curve shows that the speed would increase 37% over that at sea level, or 28% over that at 10,000 feet. The peak of this particular curve ($\Lambda = 20$) is at 47,500 feet. To improve the increases above mentioned, it would be necessary to decrease the value of Λ which, as previously explained, could be done by increased power, decreased weight, and, particularly, by increased span. This will probably be done in practice to a sufficient extent at least to compensate for any speed decrease incident to reduction of Reynold's Number. From a practical standpoint, however, when flight is made at much above 12,000 feet, it is necessary to provide additional oxygen for the passengers and crew, and when above 20,000 feet it is, in addition, necessary to add considerable weight to supercharge the engines and also to increase the pressure in the cabin to an amount approximating that at sea level. It is estimated that an airplane designed for flying at 35,000 feet will be about 7% heavier than if the airplane, similar otherwise, were equipped to fly at 10,000 feet. Therefore, the real advantage of flying at 35,000 feet rather than 10,000 feet is not the 28% increased speed mentioned above but actually 25%, estimated when taking account in the value of effective Λ of the increased weight involved to make such high altitude flying possible and practicable. There will be a further reduction in effective speed increase because of loss of speed when climbing to cruising altitude, not entirely recovered by the more rapid speed of the descending glide. A 21% overall improvement should actually be realized. The benefits of 21% improvement in speed are such, when applied to any formula for transport figure of merit as to make high altitude flying not only desirable but, the author feels, inevitable. This is on the basis of straight economics, aside from the very great advantage accruing from better weather, greater comfort, greater freedom from "bumps," and other similar items gained at high altitude. Another gain in speed can be realized through the possibility of greater vertical range to permit the pilot to select a favoring or, at least, a more favorable wind.

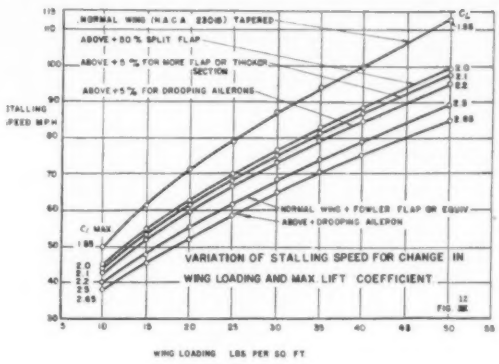
NORMAL WING (N.A.C.A. 23018) TAPERED
ABOVE + 50% SPLIT FLAP
ABOVE + 5 % FOR MORE FLAP OR THICKER SECTION
ABOVE + 5 % FOR DROOPING AILERONS
STALLING SPEED MPH
NORMAL WING + FOWLER FLAP OR EQUIV.
ABOVE + DROOPING AILERON
VARIATION OF STALLING SPEED FOR CHANGE IN
WING LOADING AND MAX. LIFT COEFFICIENT
WING LOADING LBS PER SQ FT

Fig. 12.

Wing Loading

Great progress has been made in the last five years in improving speed through increasing wing loading. From wing loadings which averaged 14 lbs. per sq. ft. a few years ago, there are now wing loadings of about 20 lbs. per sq. ft., with over 25 lbs. per sq. ft. in special cases. The limitation on wing loading is landing speed and in Fig. 12 there are shown curves of stalling speed plotted against wing loading with lift coefficient as parameter. It is seen from these curves that with a wing loading of 20 lbs. per sq. ft., the stalling speed will range from 71 m.p.h. to 54 m.p.h., depending on the use of a normal wing as against such wing with all known high-lift creating devices attached. At the present time, using partial span split flaps, lift coefficients of two are the rule, giving a stalling speed of about 62 m.p.h. for a 20 lbs. per sq. ft. wing loading. It is believed that improvement in these high-lift devices will continue and will permit wing loadings of 25, and finally 30 lbs. per sq. ft. for landplanes, and slightly more for flying boats, without exceeding a reasonable landing speed. It should be realized that the landing speed decreases as a given trip proceeds, due to decreased gross weight caused by depletion of fuel. With increasing freedom from forced landings, brought about by improved reliability of the powerplant, plus the use of more power units in a given airplane and the accompanying ability of such airplane (particularly when using constant speed full feathering propellers) to fly on less than its total number of

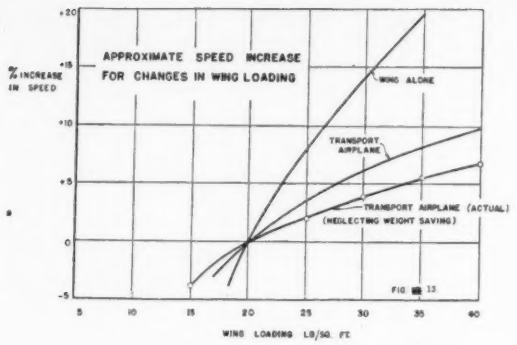
APPROXIMATE SPEED INCREASE FOR CHANGES IN WING LOADING
% INCREASE IN SPEED
WING ALONE
TRANSPORT AIRPLANE
TRANSPORT AIRPLANE (ACTUAL) (NEGLECTING WEIGHT SAVING)
WING LOADING LB/SQ. FT.

FIG. 13.

powerplants, it will become safe to compute the landing speed on the basis of the weight at the conclusion of the trip.

Takeoff distance, as well as landing speed, contributes to wing loading limitations. In this case, improvement has been made by the advent of the constant speed propeller and the improved slotted flap. It is likely that in the future the "assisted" takeoff will add another increment of improvement to distance of takeoff, thus permitting landing speed to remain the ultimately important limitation to increase in wing loading. Such "assisted" takeoff may be by means of catapult launchings, as now used for military seaplanes from battleships or cruisers, or by the Mayo Composite principle now being tried out in England.

In Fig. 13 is shown roughly the effect which may be anticipated with such increase in wing loading. Using 20 lbs. per sq. ft. as present normal transport wing loading, computations have shown that a particular current transport plane would gain a speed increase of just under 5% by increasing its wing loading to 30 lbs. per sq. ft. Including resultant weight saving, not appearing in the computations, the actual increase would be about 6%. The uppermost curve of Fig. 13 shows the effect on a wing alone. As this flying wing condition is approached in actual designs, it may be anticipated that the gain in speed incident to increased wing loading will be slightly greater than the curve the author has shown as "transport airplane." If, by catapulting, composite aircraft takeoff, or other means of "assisted" takeoff, takeoff distance limitations are removed, designing for 40 lbs. per sq. ft. is justified, then the increase in speed will be about 10%.

Effect of Weight

If, by more refined structural methods, better materials, or other means, weight can be decreased, it is apparent that the whole resultant airplane will be smaller and will have less drag. In Fig. 14 a very approximate curve is shown indicating how increased weight results in a loss of maximum speed. The effect is not great and it is doubtful as to whether a particularly large gain in speed from this source may be anticipated in view of the need for increasing weight by including added items which contribute to greater comfort. These may counterbalance any structural decrease likely to be attained. Roughly, a 10% change in weight, which is very large indeed, would result in a change in speed of about 3%.

Airplane Efficiency

The question may now be asked as to just how efficient our present airplanes are in comparison with those of the past, and as a result, what improvements are possible in the future?

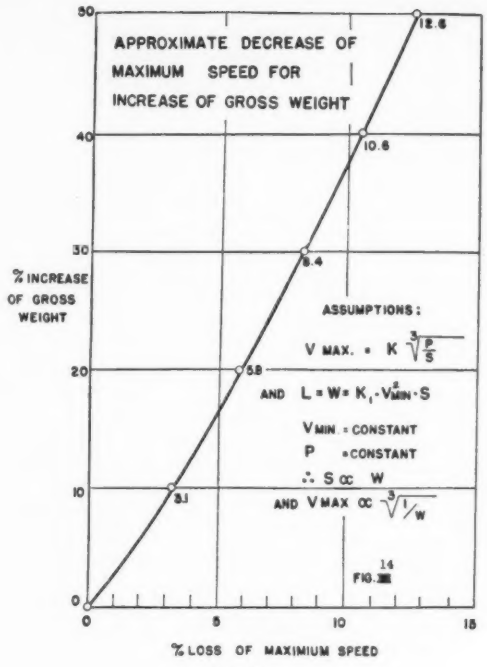

FIG. 14.

In 1929, B. Melville Jones gave a most important lecture dealing with what he called the "streamlined airplane." In this lecture he developed the thought that the frictional drag is all that it should be necessary for the powerplant to overcome in pulling the airplane through the air. He developed curves to show the necessary power per thousand pounds of weight to overcome this required friction at varying speeds and for varying values of wing and span loading. He then compared these curves for the "streamlined airplane" with then current practice with rather remarkable results. The importance of Jones' contribution was such that the author quotes herewith a brief extract from his lecture as published in the Journal of the Royal Aeronautical Society for May, 1929:

"Ever since I first began to study aeronautics I have been annoyed by the vast gap which has existed between the power actually expended on mechanical flight and the power ultimately necessary for flight in a correctly shaped aeroplane. * * * * *Apparently, large commercial aeroplanes of today would, were they ideally streamlined, either fly at the present top speed for one-third of the present power, or alternately, travel some sixty miles an hour faster for the same power. Two-thirds of the power used by these aeroplanes is being expended on the generation of turbulence which, from the aerodynamic standpoint, is unnecessary.* * * * * *It is not suggested that it is easy to design a streamlined aeroplane which will be also a practicable machine, but the immense saving in power, and therefore in fuel consumption which would apparently follow such a step, forces me to the belief that design will evolve steadily in this direction and that the ultimate aeroplane will be as well streamlined on the whole of its external surfaces as, say the bottom of a racing yacht or the externals of an albatross. I am fortified in this belief by surveying the animal kingdom.* * * * * *The compromise with structural difficulty was no doubt as difficult for them as for us, but it has ended in the complete triumph of the external form. We can only hope that it will not take us so long to reach this point as, if we are to believe the comparative anatomists, it took them."*

During the past six months, analyses of the type first proposed by Jones have been made by Hoerner, Rolf, Crowe and Wood and others. The author proposes here to extend the idea to include the wing as having drag defined as skin friction drag plus an increment for pressure, as previously described. The analyses of the last six months have shown a vast improvement in modern airplanes from the conditions that maintained in 1928, from which year the examples that Jones cited were derived, thus indicating that it did not take (as indeed Jones hoped it would not) the tremendous time to improve the airplane that it did for birds. In Fig. 15 the curves developed by Jones are shown together with additional ones to cover the case of 20 and 25 lbs. per sq. ft. wing loadings now existant. The author has dotted in the average values for 1928 airplanes as taken from the Jones' Chart. It will be seen here that, on the average, the wasted horsepower was 66% and the actual speed was approximately 65% of the streamline speed. A few modern transports spotted on the same

TABLE 2

AIRPLANE EFFICIENCIES

	ITEM	UNIT	FORMULA	1929 ROBIN CHALLENGER EXTERNALLY BRACED MONOPLANE EXPOSED LAND. GEAR COMMERCIAL	1932 CONDOR CYCLONE (2) EXTERNALLY BRACED BIPLANE RETRACTING LAND. GEAR COMMERCIAL	1934 COUPE LAMBERT INTERNALLY BRACED MONOPLANE EXPOSED LAND. GEAR COMMERCIAL	1933 DOUGLAS CYCLONE (2) INTERNALLY BRACED MONOPLANE RETRACTING LAND. GEAR COMMERCIAL	1935 HAWK III CYCLONE EXTERNALLY BRACED BIPLANE RETRACTING LANDING GR. MILITARY	1936 PURSUIT MODERN INTERNALLY BRACED MONOPLANE RETRACTING LAND. GEAR MILITARY	1936 LIGHT BOMBER MODERN INTERNALLY BRACED MONOPLANE RETRACTING LAND. GEAR MILITARY	1934 GEE BEE SUPER SPORTSTER GTYPSY (2) INTERNALLY BRACED MONOPLANE RETRACTING LAND. GEAR RACER	1933 HEINKEL HE-5 BMW INTERNALLY BRACED MONOPLANE RETRACTING LAND. GEAR COMMERCIAL	1940 TRANSPORT 1938/40 INTERNALLY BRACED MONOPLANE RETRACTING LAND. GEAR COMMERCIAL
1	GROSS WEIGHT	#	W	2600	17600	1800	18200	4406			5660	7380	60000
2	WING AREA	D'	S GROSS	242	1330	173	942	262			212.5	283	2230
		D'	S NET	224	1208	150	838	250			190	362	2000
3	SPEED V/MAX.	MPH	V/MAX	118	189	127	215	239			238	234	212 (Cruise)
4	" "	FT/SEC	"	173	277	186	312	352			344	343	311
5	ALTITUDE for V/MAX.	FT	H	Sea Level	8000	Sea Level	8000	11600			Sea Level	Sea Level	30000
			ρ	.002378	.001869	.002378	.001869	.001670			.002378	.002378	.000889
				.000159	.0001925	.000194	.0001925	.00021			.000194	.000194	.00034
6	HORSEPOWER for V/MAX.	HP		165	1430	96	1430	730			670	680	2400 (Cruise)
7	"Q" (V/MAX. @ H)	Q	ρV²/2	35.6	71.9	41.1	91	107.5			140.5	128.5	43
8	WING LOADING	#/D'	W/S	10.7	13.2	10.4	19.3	16.8			26.5	26.75	26.9
9	POWER LOADING	#/HP	W/HP	14.1	12.2	18.7	12.7	6.9			11.5	11.18	25.0 (Cruise)
10	PROPELLER EFFICIENCY	O/O	η	80	80	80	82	77.1			80	81	80
11	CHORD	FT	C (WING)	6	8.86	5.32	11.1	8.02			5.5	6.55	19
			C (TAIL)	3	5	3	6	2.5			4	4.5	10
12	SPAN	FT	D	41	87.5	36	85	31.5			44	48.5	183.2
13	FUSELAGE LENGTH	FT	L	25.1	49.1	25.4	62	21			29	38	100
14	ASPECT RATIO		D²/S=(AR)	6.36	5.76	7.1	7.66	4.26			9.1	6	10.57
15	WETTED AREA - WING	D'	SNET X2.07	464	2500	311	1775	518			394	730	4180
16	" " - FUSELAGE	D'		230	1000	220	1260	247			256	366	3400
17	" " - TAIL	D'	ATAIL X2.03	117	518	71	481	96			87	161	880
18	" " - TOTAL	D'	AW	849	4273	649	3691	886			763	1342	8900
19	C_L @ V/MAX.		W/qS	.301	.163	.253	.212	.167			.186	.155	.025
20	DRAG - TOTAL	#	550XηXHP/VMAX	470	2270	227	2070	905	910	1850	800	857	5400
		O/O	TOTAL	100	100	100	100	100	100	100	100	100	100
21	" - INDUCED	#	[CL²π/(AR)][qS]	36	178	20	161	82	43	76	36	83	1130
		O/O		8	8	9	8	6	5	4	6	6	13
22	" - COOLING	#	550X(1-η)XHP/VMAX	23	114	12	103	46	45	95	30	43	170
		O/O		5	5	5	5	5	5	5	5	5	2
23	" - FRICTION + PRESSURE + WASTED	#	Dr - DL - Dc = Dw	411	1980	196	1806	807	822	1691	534	761	2100
24	REYNOLDS NUMBER	R	VL/ν (AVERAGE-FUS-WING-TAIL)	1.2×10^7	2.6×10^7	1.5×10^7	4.5×10^7	1.6×10^7	2.2×10^7	3.5×10^7	2.9×10^7	3.3×10^7	4.5×10^7
25	FUSELAGE U_F	FT/SEC	1.10 X VMAX	190	305	205	344	388	468	433	378	378	342
26	" REYNOLDS NUMBER	R_F	$U_F L_F/\nu$	3×10^7	7.8×10^7	3.3×10^7	1.1×10^8	3.9×10^7	5.2×10^7	8.9×10^7	6.9×10^7	9×10^7	1×10^8
27	C_{D_F} for R_F		(FROM CURVE)	.00245	.00215	.00240	.00203	.00235	.00227	.00208	.00217	.00207	.00206
28	D_{F_F}	#	$C_{DF} X \rho A_{FUS} U_F^2/2$	24	167	26	283	73	96	177	95	129	364
29	D_{F_T}	#	DFT X 30/70	10	80	11	121	31	41	76	41	55	156
30	WING U_W	FT/SEC	1.10 X VMAX	190	305	205	344	388	468	433	378	378	342
31	R_W	R_W	$U_W C/\nu$	7×10^6	1.4×10^7	6.9×10^6	2×10^7	9.3×10^6	1.4×10^7	2.3×10^7	1.3×10^7	1.6×10^7	1.9×10^7
32	C_{D_W}		(FROM CURVE)	.00292	.00270	.00293	.00275	.00283	.00270	.00256	.00272	.00273	.00276
33	D_{F_W}	#	$C_{DW} X \rho A_{WW} U_W^2/2$	68	689	45	540	184	198	511	182	328	890
34	D_{F_W}	#	DFW X 20/80	15	147	11	135	46	49	128	45	84	147
35	TAIL U_T	FT/SEC	1.05 X VMAX.	181	291	196	329	370	446	413	361	361	327
36	R_T	R_T	$U_T C_T/\nu$	3.5×10^6	7.6×10^6	3.7×10^6	1×10^7	4.4×10^6	7×10^6	1.4×10^7	9.1×10^6	1×10^7	9.6×10^6
37	$C_{D_{FT}}$		(FROM CURVE)	.00310	.00288	.00308	.00280	.00305	.00292	.00270	.00283	.00280	.00281
38	D_{F_T}	#	$C_{DFT} X \rho A_{WT} U_T^2/2$	14	118	10	136	33	87	169	28	79	118
39	D_{F_T}	#	DFT X 10/90	2	13	1	15	4	10	19	4	8	13
40	AIRPLANE D_{F_A}	#	DFF + DFW + DFT	96	894	81	959	290	380	857	315	537	1072
		O/O		20	39	36	46	32	42	46	52	63	32
41	D_{P_A}	#	DPP + DPW + DPT	27	240	23	271	81	100	223	90	147	316
		O/O		6	11	10	13	9	11	12	15	17	9
42	$D_{TOTAL\ F\ P}$	#	DFA + DPA	123	1134	104	1230	371	480	1080	405	684	1388
43	D_{WASTED}	#	ITEM 23 MINUS ITEM 42	289	846	91	576	436	342	601	129	77	712
		O/O		61	37	40	28	49	37	33	22	9	21
44	EFFICIENCY		$\sqrt[3]{1.00 - \frac{D_{WASTED}}{D_{TOTAL}}}$	73.8	86	84.5	89.6	80.5	86	87.6	92.2	97	92.8
45	STREAMLINE SPEED .	MPH	ITEM 3 ÷ ITEM 44	161	220	150	238	294	280	284	256	241	229
46	WARNER'S "K"	Kw	VMAX/∛HP/S6	129	170	164	171	163	169	186	180	196	149 (Cruise)

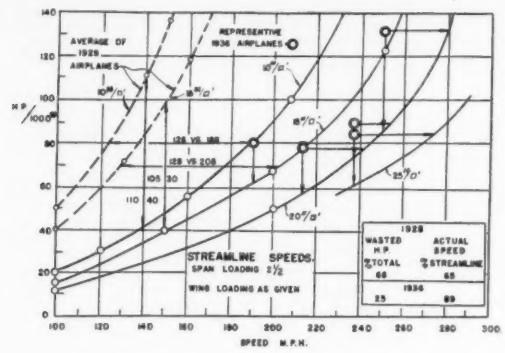

FIG. 15.

curves, and having wing loadings of 15, 20 and 25 lbs. per sq. ft. show such improvement that now the wasted horsepower is but 25%, and the actual speeds are 89% of the streamline speeds. It is this latter ratio that the author terms airplane efficiency.

In Table 2 are the computations used to obtain the airplane efficiency and the streamline speed for several airplanes, mostly modern, but some going back to the period used by Jones. The formula used for determining each item of the chart is given and as so much of the data has been previously discussed in this paper, it is believed that further mention of the method is unnecessary. One or two statements, however, will serve to clarify the reasoning used in including or excluding drag items in my chart. The cooling drag has been uniformly placed at five per cent of the total, first because of the extreme difficulty in determining actual cooling drag, and secondly, because it is believed that at present it is not particularly difficult and certainly not impossible, to attain this figure. Next, it will be noted in the table that slipstream drag, *i.e.*, the increment of drag due to increased velocity in the propeller wake, is omitted. This is done for two reasons. First, because of its almost negligible effect, averaging less than 2% on all airplanes measured, and secondly, because it is, in part, included by the slightly high figure used for surface velocity increment in the case of the fuselage, wings, and the tail (10% for the fuselage and the wings as against about 9% increment from pressure distribution).

It will be further noted that friction and pressure drags have been segregated to determine the per cent of the total which each represents. When the induced drag, the cooling drag, the friction drag, and the pressure drag are deducted from the total drag, the wasted drag which is created by unnecessary shape turbulence, excess friction, interference turbulence and the drag of unnecessary parts is obtained. The cube root of the difference of one minus the wasted drag over total drag, gives the airplane efficiency, and the actual speed divided by this efficiency gives the streamline speed.

TABLE 3

Extract from Table 2 Illustrating Specific Working of Method

Item	*Robin (1929)*	*Douglas DC-2*	*Heinkel HE-3*
% Drag—Induced.....	8	8	6
% Drag—Cooling.....	5	5	5
% Drag—Skin Friction	20	46	63
% Drag—Pressure....	6	13	17
% Drag—Wasted.....	61	28	9
Airplane Efficiency ...	73.8	89.6	97
Actual Speed	118	213	234
Streamline Speed	161	238	241

For the sake of emphasis, the author has, in Table 3, recapitulated this data for one airplane built in 1929 and two typical modern airplanes. Table 3 illustrates the very high degree of efficiency now attained in the Douglas DC-2, and the phenomenal efficiency of the Heinkel. The Heinkel plane has utilized every modern idea for giving perfection of surface, perfection of wing shape, perfection of wing-fuselage connection, all of which combine in giving it the efficiency shown. There is complete freedom from protuberances such as rivet heads, window sills, and the like, as well as a highly aerodynamically efficient wing planform. In order to improve upon the efficiency shown in the Heinkel, changes in wing loading possible through higher-lift devices, further reductions in cooling drag, improvements in weight, and flight at high altitude, will be necessary.

Table 2 also shows the values for the Everling Factor, known in this country as Warner's K and which is represented by:

$$K = V_{max.} / \sqrt[3]{P/S\sigma}$$

The order of merit indicated by this factor is not substantially changed from that obtained by the airplane efficiency factor as derived in Table 2. However, several of the assumptions used in applying the Warner's K formula are rapidly becoming invalidated so that it is believed that the new formula is desirable for more refined analyses, although the other will undoubtedly continue to be most useful as a quick method to use in race handicapping.

FUTURE IMPROVEMENT IN SPEED

Assuming the DC-2 as the standard of modern comfortable air transports, Table 4 indicates the speed improvement which it is reasonable to expect in the next few years:

TABLE 4

Item	Description	% Speed Increase
Elimination of Wasted Drag...	Further improvements in streamline shape as well as improvements in design of windshields and similar items; improvements in surface smoothness by polishing and elimination of exposed rivet heads, sills, lap joints, etc.; reduction of interference by better fillets, etc.	10%
Elimination of Unnecessary Parasite Drag.....	Enclosed motors with reduced nacelle size; perfect landing gear retraction; elimination of exposed horns, hinges, and similar items	4%
Reduction of Induced Drag....	Higher aspect ratios; elliptical wing shapes	2%
Wing Efficiency Improvement..	More perfect taper; thinner wings thru greater structural efficiency; improved wing sections	2%
Propeller Efficiency Improvement.....	Operation at better V/ND; improved blade sections; less interference	2%
Reduced Weight.....	Some increase in size better materials; improved structural design	3%
Wing Loading.....	Improved Flaps and Section Characteristics	5%
Altitude Flying.....	Flying at 35,000 ft. with supercharged cabins as against 10,000 ft. at present	21%

The sum of the above improvements gives the probable gain in the next few years, *i.e.*, 49%. It is interesting to note that the amount first prognosticated for a transport airplane, as given in Fig. 1, is approximately 50% more than present speeds. The preponderance of advantage of high altitude flying is noteworthy with elimination of wasted drag as next in importance.

Further Possibilities

In the above the author has given what appears likely to occur in the next few years and which is certainly within grasp from the standpoint of the state of the art and science at the present time. As to the likelihood of going even further thereafter, even though the curves in Fig. 1 are shown as flattening out, there are possibilities. One such is in reducing cooling drag, even to the extent of eliminating it entirely by utilization of the heat from the cooling medium and from the exhaust for the supplying of forward thrust along the lines of jet propulsion. There is also the possibility of going even further in the matter of wing loading, reaching loadings of 40 lbs. per sq. ft. through "assisted" takeoff. There may also be possibilities in decreasing power loading from the present values. However, here the author feels that much decrease will not be warranted through the application of any recognized criterion for transport efficiency, as the cost of speed improvement through extra power will be more than the resultant improvement in velocity. There is the additional possibility as regards improvement of thermal efficiency of the power unit which is, at present, of the order of 30%.

Perhaps the altitude of 35,000 feet used above can be increased to gain a further increment of speed. However, the author is inclined to believe that there will be rapidly diminishing returns from flying much higher. The 35,000 feet chosen represents about the greatest height at which engine power can be maintained at sea level ratings with two stages of supercharging. Also the problems of cabin pressurization will increase rapidly as wall pressure differentials of over 1300 lbs. per sq. ft. will maintain. At 35,000 feet the comfort and navigational advantages of high altitude flying are attained, so, all things considered, about this height seems likely to represent an optimum.

And finally, there is the extremely remote possibility that a means of continuing laminar flow in operating Reynold's numbers, will be discovered the limit of which possibility, compared with present attainment, will be a reduction in skin friction drag coefficient to about one-ninth of its present value! It will, however, require new discovery based on painstaking research for each mile per hour improvement in speed beyond the limits shown in Fig. 1 for transport cruising speeds and for racer record speeds.

It should here be mentioned that at a figure of slightly over 500 m.p.h. the factor of compressibility, neglected throughout in the development of aerodynamic theory, will commence to play an important part which will eventually at slightly higher speeds represent a probable ultimate limit. Tests have shown that at velocities of about 450 m.p.h. (six-tenths the speed of sound), a breakdown in flow begins to occur, caused by a shock or compression burble after which a greatly increased drag and decreased lift occur. As the velocity of sound is proportional to the square root of absolute temperature and therefore decreases with increasing altitude, it is apparent that this final speed limit will be less as altitude increases, even though from a practical and economic standpoint flight at high altitude and speeds under this limit is most desirable.

Conclusion

In this paper the author has attempted to give you an outline of the state of the art with reference to the development of speed in airplanes and to describe some of the lines along which further improvement in speed may be expected. Certainly, twelve hour transcontinental and eighteen hour transatlantic passenger crossings are not far off.

Certain limits of speed have been indicated which the author believes likely and is reasonably sure will be reached in the not too distant future. The author is inclined to hedge a little however, on too firm a commitment in setting such limits. In all matters of scientific and engineering advancement, the following words, reported to have been given us by the great explorer Nansen, must be borne in mind.

"The difficult is that which requires a little time and the impossible is that which requires a little longer time."

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Notes on the Construction of Integral Fuel Tanks for Airplanes

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(Received November 10, 1936)

Summary

THE integral or built-in tank is one way of constructing more efficient airplane structures, since it utilizes the primary members and saves weight and space. A good tank is dependent upon good seams; demanding an insoluble and stable sealing medium. Low rivet stresses and careful workmanship are also important. The most widely used methods of sealing seams are those using bakelite varnish or one of the synthetic rubber compounds such as "Thiokol" or "Du Prene". A description of the methods of using the sealants is given. There are several ways of making the seams and joints and their use depends upon the locality in which the tank is placed. The best type of seam is that which is securely fastened at the ends and has a flexing portion between. Corners and structural members going through the tank offer the most difficulty. These should be fastened in with properly shaped castings, stamped or welded fittings; the former two being preferable due to reliability and low cost. Some estimates of the weight of joints are given showing a substantial saving in weight through use of the built-in tank.

Introduction

The necessity of carrying sufficient fuel for long distance flights and at the same time carrying a reasonable payload has been one of the major problems of long distance air transport operation. Air line operators constantly urge the constructors to build more efficient and economical structures; that they carry a greater payload per pound of structural weight and provide further capacity for cargo and passengers. The built-in gasoline tank is one method of saving weight and space by using the structural members to form the fuel tanks.

Advantage of the Built-in Tank

Up to the present time, there has been little interest shown or experimental work done on this type of tank. This lack does not do justice to the saving that may be accomplished through use of the primary structure as a gasoline tank. Such tanks can be built into the wing, between spars; in the fuselage, underneath the cabin proper, or in the compartments of boat hulls and floats. The natural curvature and bow of the primary structure in these regions are excellent shapes for tanks, due to the stability of thin curved sheets under internal pressure. A good built-in fuel tank, besides saving weight, should cost no more to construct or be any more difficult to maintain than the ordinary separate type of tank. Repairs on the built-in tank will in most cases mean tightening of rivets and re-caulking seams, all of which can be done without removal of tank straps, skin-covers or equipment adjacent to the tank as is generally the case with the separate type of tank. The addition of the integral tanks to a plane will assist in meeting the specifications for water tight compartments which are now desirable on many commercial and military ships since they afford an additional means of buoyancy. They also permit one to utilize the full capacity of the space allotted to fuel tanks, a very important item in large transport planes. With an eye toward the not so distant future, experience gained in building this type of tank can be used to good advantage in developing air tight construction for the cabins of stratosphere planes and light construction for skin type radiators for cooling high powered engines.

Methods of Sealing

Built-in tanks have met with slight success and are not favorably considered due to leakage of the seams. The opening of the seam may be caused by one or more of several conditions such as: (1) vibration; (2) weaving of the structure; (3) failure of rivets; (4) loosening of the rivet joints; and (5) erosion or solubility of the joint sealing compound in contact with gasoline. The success of the built-in tank depends primarily upon good seams; which in turn are dependent upon an efficient means of sealing and the flexibility of the joint. The location, proper application of the caulking or sealing material, rivet stresses, and workmanship are also important factors.

Before applying any type of sealant to the metal, the part should be carefully cleaned of dirt and grease. A light rubbing with steel wool to brighten the surface is recommended.

Bakelite varnish, spar varnish, and bitumastic have all been tried as a sealing compound on early types of tanks. The latter two, however, are somewhat soluble in gasoline and are attacked by gasoline vapor. Bakelite varnish has been preferred and is one of the most efficient means of sealing. It is not soluble in ordinary grades of gasoline (those without Benzol) and is

easily applied to the joints. This is done by one of two methods:

(1) The members which are to be sealed together are coated with a heavy bakelite oil-resin combination (Spec. XV-2108, or tentative Navy Specification V-13), and only allowed to dry sufficiently to remove the solvent, after which they are pressed together and riveted.

(2) A strip of soft cotton flannel, friction tape, twilled tape or edging tape is thoroughly impregnated with the varnish, in this case reduced down with bakelite thinner for better penetration, and finally before the strip is inserted in the seam it is given a fresh coat of the heavier varnish and allowed to partially air-dry until the tape is sticky. It is sealed in the seam while it still has a great degree of tack.

Although the joint may be subjected to weaving and vibration, the bakelite varnish forms an elastic film and will stand up over long periods without leakage.[1]

Seams Made with Synthetic Rubber

In many cases where the structure is stressed to a high degree; where there may be excessive weaving, vibration, or wracking, or in planes in which the use of high-test Benzol-leaded gasoline is expected, the sealing strip made with the bakelite varnish specified may be susceptible to leakage since the varnish is solvent in Benzol. It is in these cases that the slightly heavier joint made with a synthetic rubber sealing strip is used.

"Thiokol", one of the first forms of synthetic rubber, has been used successfully. It has been tested and approved by the Army Air Corps for fuel resistant coatings and hose. It is insoluble in gasoline and not affected by hydro-carbons. The coatings are supplied and can be used in the unvulcanized state.

The coatings are applied in several manners depending upon the type of "Thiokol" used.

(1) Using a fine brush about ¾ inch wide, apply a thin coat of "Thiokol" (Specification G–18) to the parts that are to be riveted together and allow to dry for approximately 30 minutes. Successive coats are then applied with sufficient time to dry between each until a thickness of 1/32 to 1/16 inch is applied. It is best to put on a light first coat, using a very thin solution by thinning with "Thiokol" thinner No. 2 or ethylene dichloride. This can be followed with heavier coats as stated above. The parts are riveted together while they are slightly wet. All rivets should be dipped in the coating before they are inserted in the members.

(2) "Thiokol" coating in the form of a stiff dough (Specification G–20) riveted between the members after a light coat of thinned "Thiokol" has been applied to the metal.

(3) A stiff dough of "Thiokol" is spread on cotton cloth and used as a gasket. The gasket is cemented to the metal parts with a suitable coat of "Thiokol" diluted with thinner.

(4) To seal the tank completely, a thin coat of "Thiokol" can be sprayed along the edge of inside seams before putting on the covering sheet. Outside seams can be sprayed through inspection holes after assembly. The standard commercial type spray gun is used. The coating can be sprayed as supplied or diluted to a consistency suiting the equipment. This treatment will mask out any pin holes that may occur.

Another form of synthetic rubber which is made by the Du Pont Company under the trade name of "Du Prene" possesses similar characteristics to those of "Thiokol". "Du Prene" may also be used in several different ways:

(1) The material is bought in sheets and cut into strips. The strip is then cemented to the members with a thin layer of "Du Prene" cement and the parts riveted together.

(2) A thick coat of "Du Prene" in liquid form is painted on the metal surfaces to be riveted and allowed to air dry. Another coat, partially thinned down, is then applied over the first coat after which the pieces are riveted together.

(3) A thinly "Du Prene" coated fabric of cotton flannel or twilled cloth is used as a gasket. The "Du Prene" is allowed to thoroughly dry on the fabric and then cemented to the parts with "Du Prene" cement.

Joints made with synthetic rubber have the added advantage of being able to absorb much of the vibration, weaving or shock loads that occur in the structure.

Riveting

In riveting the seams, the rivet should always be dipped in the sealing medium before driving. Where strip synthetic rubber is used, the rivet should be dipped in cement of the same type. The spacing of rivets should not exceed 4 to 6 times the diameter of rivets used. Two or more rows of staggered rivets should be driven, the spacing between rows being 2½ to 3¼ times the rivet diameter. Rivet stresses should be about 20–30% less in bearing and shear than normally used (approximately 50–55,000 lbs. per sq. in.). The thickness of the rivet head should be about 40% of the shank diameter and the head diameter 50% greater than shank diameter. Careful workmanship and good heading of the rivets is essential for a good seam. Where expense is not a govern-

[1] Reference in this case is made to the round-the-world flight of Richard Light of New Haven, Connecticut. The flight was made during the latter part of 1934 in a Bellanca Pacemaker equipped with Edo Floats having built-in gas tanks. Light reported landings made under various trying conditions of weather and climate ranging from cold stormy days in Iceland to warm moist days in India and around the neighborhood of the Amazon River. He reported exceedingly good service under severe conditions and few, if any, leaks.

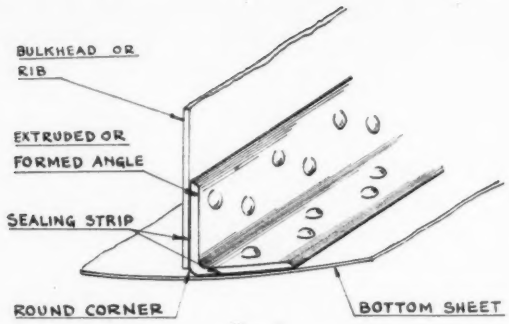

FIG. 1.

ing factor, the Navy [2] type of rivet should be used, *i.e.* by applying a soft aluminum edging strip to back up the rivets.

TYPES OF SEAMS

There are several types of seams and the successful use of each depends upon the locality in which the seam is used. The type shown in Fig. 1 can be used in such places where the parts to be joined are flat sheets or smooth curves and no intricate shapes or connections are involved. This type of seam has had wide use in fuselages, floats, wings, and hulls. It is the lightest and simplest type of construction. The seam is made up of a formed or extruded angle sufficiently wide enough to get two rows of staggered rivets. Between this angle and the tank members is placed the sealing strip.

In such places as the wing, floats, or hull bottoms, where there are important structural members, the type of joint shown in Fig. 2 may be used. The joint as illustrated is used on the multi-spar wing of the Seversky basic training plane. The gasoline compartment is located between spars of the wing center section. The spars and top and bottom covers serve as baffles and ends. The seam at the bottom is a simple one made similar to that shown in Fig. 1. The bottom skin is flat sheet stiffened by longitudinal stringers. The stringers do not run through the tank as continuous members; they are stopped at the end ribs and fastened to clips carrying the load to similar clip fittings on the outside of the tank. The seam at the top is made of a formed or stamped plate which is securely riveted together with a sealing strip of bakelite varnish, (Specification XV–2108) impregnated tape between members. The plate or plates are fastened to the ribs and the corrugated top sheet is then set into the formed plates with a sealing strip between the faying surfaces. All faying surfaces are sealed by using 4 oz. canton flannel or cotton tape impregnated with bakelite varnish. The longitudinal stiffeners along the bottom skin between tank ends are securely clipped to the intermediate ribs inside of the tank. The ribs have large

[2] Navy Specification SR-20, *Specification for Riveted Airplane Fuel and Oil Tanks.*

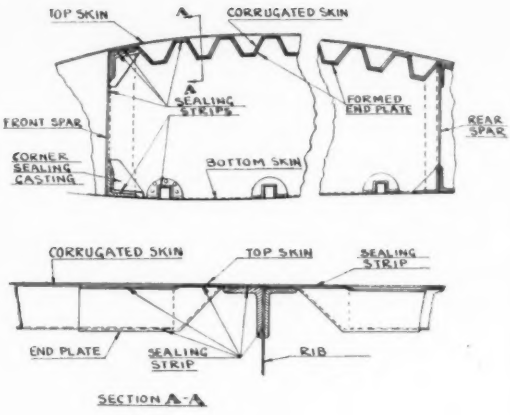

FIG. 2.

flanged lightening holes which allow free flow of the fuel between compartments. A light rolled angle is riveted across the hole to act as a stiffener. Small holes are drilled at the bottom of each rib in the tank to allow the tank to be thoroughly drained. The filler unit is placed at the outboard side of the tank just under the wing fillet. The tank sump projects slightly below the bottom skin.

The tank is given an interior coat of bakelite varnish to seal all pin holes before the bottom skin is put on. The aileron and elevator controls run through a tunnel in the tank; formed by rolling a flat sheet into a cylinder and double riveting the seam which is made with bakelite varnish and tape. The tunnel is fastened at the first and fourth spars, which are tank sides, with suitable aluminum alloy rings and gaskets made of flannel and bakelite varnish.

A type of construction of somewhat similar nature, using "Du Prene" as a sealant has been used on a monococque wing. The skin forming the upper and lower surfaces of the wing is reinforced by zee-shaped longitudinal stringers which are spot welded in place. As on the Seversky plane, the stringers do not run through the tank but are fastened to clips which carry the loads through the tank to similar members on the opposite side of the tank ribs. The sealing strips along the spars and tank end ribs are "Du Prene" in the form of thin strips. These are cemented in place with "Du Prene" cement. The outside seams of the tank are given a liberal coating of liquid "Du Prene". The spars and the end ribs serving as the ends of the tank are not spot welded but riveted in place.

Although this type of structure does away with holes in end ribs for carry-through members, attention is called to the fact that it does not allow the primary structure to be made continuous, *i.e.*, the stringers, or corrugations, are broken at the ribs. The structure can be carried through and made more efficient by using the type of joint shown in Fig. 3. This type of construction increases the flexibility of the joint by fasten-

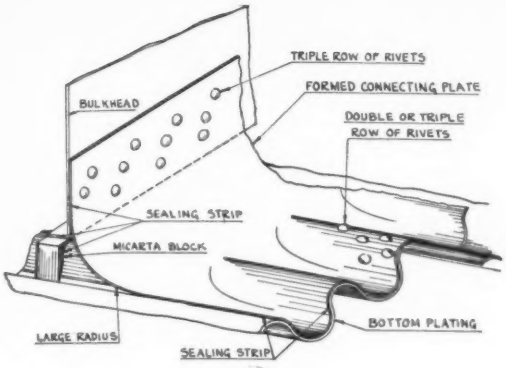

FIG. 3.

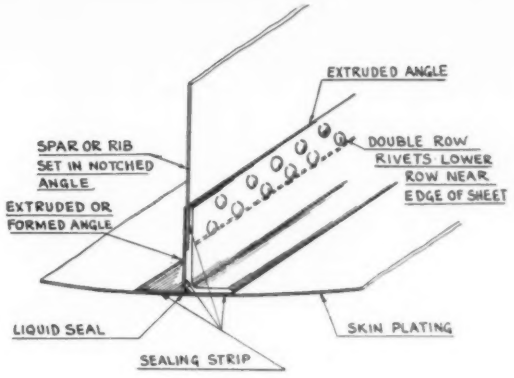
EXTRUDED ANGLE
SPAR OR RIB SET IN NOTCHED ANGLE
DOUBLE ROW RIVETS LOWER ROW NEAR EDGE OF SHEET
EXTRUDED OR FORMED ANGLE
LIQUID SEAL
SKIN PLATING
SEALING STRIP

FIG. 4.

ing the two ends securely and allowing the intervening portion to flex with the structure. The joint is essentially simpler to make tight than that shown in Fig. 2. The bulkhead or rib is flanged at the bottom and fastened to the tops of the corrugation. The space between the flanges of the frames and the valleys of the corrugation is filled with a snug fitting micarta block set in place with a sealing strip and held by a Parker Kalon screw, through the flange; or the frame may be flanged to fit the corrugations at tops and bottoms. The latter, however, is a difficult operation. In some cases, an additional edging strip of softer metal, such as aluminum, may be added to permit the rivets to be driven more securely.

A seam similar to this has been used in the hull tanks and sea-wing tanks of the Martin Clipper ships. The tanks are built integral with the hull structure below the cabin flooring and in the sea-wings on either side. The seams are made with canton flannel impregnated with bakelite varnish. The outside seams of the tank are given a liberal coating of "Thiokol" G–18.

A very ingenious seam and one of extreme flexibility has been developed by the Martin Company for use in wing tanks. (Fig. 7) The Martin Company has done a great deal of experimenting to develop satisfactory seams; they use bakelite varnish as well as "Thiokol" G–18 and G–20 for sealing. In the wing tanks, sealing between end bulkheads and the top skin corrugations is accomplished by using sponge rubber riveted between two phenol fibre plates. The drawing together of the two fibre plates squeezes the rubber out tight against the corrugations. This allows the bulkhead and top skin considerable freedom and movement under stress and at the same time maintains an effective seal. The sponge rubber is given a liberal coating of "Thiokol" before installation.

In constructing the tanks, the Martin Company was faced with the problem of reinforcing the structure due to the size of the tanks. The sides and ends had to be reinforced sufficiently to withstand the hydrostatic pressure due to the great depth and capacity. This was done by increasing the strength of the stiffeners on the inside of the spars, (Fig. 7) and on the end bulkheads. Flat plates were riveted to the stiffeners increasing their depth and a bulb section riveted to the inboard edge of the plate.

To carry the loads into the wing spars; reinforcing bulkheads, also acting as tank baffles, were installed. This permitted the bottom skin to be kept down to a small gage. Large oval lightening holes reinforced at the edges with a bulb section were cut out of the middle of these bulkheads.

It is seen that in this construction and in the types previously mentioned that the integral tank is well supported on all sides by the adjacent structure.

Another type of joint which shows good possibilities and which has stood up under severe service is shown in Fig. 4. This joint, although slightly heavier than some of those previously mentioned, has the advantage of being flexible and the very distinct feature of being self-sealing. It is used to form the seams of the gasoline compartment of the Curtiss-Wright Courtney Amphibian and on Edo floats with integral tanks. As is seen in Fig. 4, the joint is made up of two extruded or one extruded and one formed angle, with fairly large corner radii. The joint is assembled with bakelite varnish impregnated tape between all faying surfaces. The channel formed by the radii of the two angles is filled with liquid bakelite varnish pumped in under pressure with an "Alemite" grease gun. The channel should be blown out under air pressure (3–5 lbs.) before filling with varnish. The connections for pumping are usually at the corners where a suitable casting such as shown in Fig. 5 is located. When pumping, the "Alemite" fitting at one end of the groove should be removed and pumping done at the other end.

With this type of seam any leak is sealed by liquid varnish contained in the channel leaking out and solidifying upon contact with the air or fuel. The supply of varnish in the channel can be renewed at periodic overhauls. Upon close examination of Fig. 4, it is seen that one of the angles is recessed slightly to

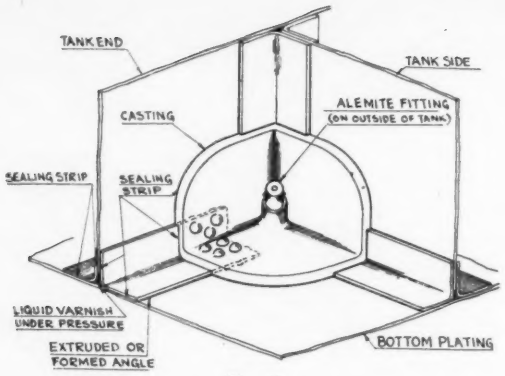

FIG. 5.

accommodate the bulkhead sheet. This is done for a very specific reason; the lower row of rivets through this part of the seam is driven quite close to the edge of the sheet. When the rivet is headed, it causes the sheet to bulge slightly and thus caulks the joint very effectively.

The fuel tank of the Courtney Amphiban[3] was built integral with the hull. It is situated just forward of the step. The bottom plating and sides of the hull served as the respective members of the gas tank. The front and top of the tank served to form a rear seat in the cabin of the plane capable of seating three persons. The back of the tank and seat were formed by a fuel and watertight bulkhead.

This same type of construction used in the Edo tank floats provides space for 150 to 500 gals. of gasoline per float (depending upon the size of the float). To withstand stresses due to hydrostatic pressure and splashing of gasoline in the compartments, the bulkheads of the tanks are reinforced by formed dural angles of tapering depth which connect the deck angles and sister keelson members. The bulkheads are further reinforced by stiffeners running athwartship. The end bulkheads of the tank are connected together by a grid-work of light dural angles on the inside of the tank. The ends of the longitudinals of the grid are fastened to the main bulkhead verticals by suitable clips and cross members of the grid are fastened to stiffeners at the sides of the float. The gridwork serves to distribute the loads throughout a large area and together with a semi-bulkhead helps to break up any large surge of fluid.

The B/J attack ships built for the Navy used a type of seam similar to that shown in Fig. 4. The tank was located in the oval shaped fuselage just behind the firewall; controls to the engine running through a tunnel built into the tank. To insure good seams, the tank was given an interior coat by filling it with 3 to 5 gals. of bakelite varnish and rotating the entire fuselage several times after which the excess varnish was drained off.

[3] The Curtiss Wright Amphibian, *Aviation*, August, 1934; *Aero Digest*, August, 1934.

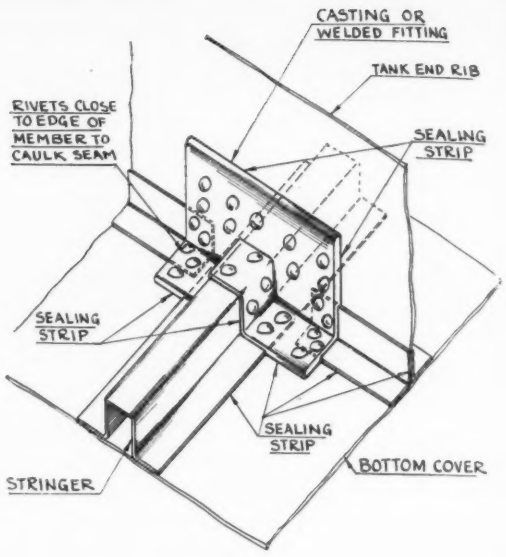

FIG. 6.

There has been some difficulty experienced with seams made with bakelite varnish in that the excess of varnish squeezed out from between the joint members or smeared on carelessly by mechanics has tended to peel off in a thin film or globules and collect around the foot valves and screens. Care should be taken that members are carefully cleaned of oil before applying the varnish and that any excess of varnish is removed. The tank should be thoroughly cleaned after completion by rinsing with Benzol to bring any excess material into solution and withdrawing it through the drain, or the interior of the tank may be completely coated with bakelite varnish.

CORNER SEAMS AND CARRYING THROUGH STRUCTURE MEMBERS

The most difficult joints to seam in the tank are those occurring at the corners or where important structural members go through the tank. The reason for this lies in the fact that there are many places through which leaks may occur. The best method of sealing such joints is through use of light aluminum alloy castings such as shown in Fig. 5 and Fig. 6 or with light sheet metal stampings. In some cases, a welded steel fitting may be used. This is not commendable since a certain amount of water is likely to get into the tank, possibly when filling or by rain, and cause corrosion of the joints even though such joints may be well insulated. Steel should only be used where the fittings are heavily loaded and cannot be replaced by castings or stampings. When designing fittings for corners and the like, there should be ample area of metal provided on the fitting to allow for sufficient closure and seaming around the joint. As previously stated, recessing the sheet in the fitting and

driving the rivets close to the edge of the sheet (approximately 1¼ diameters away) will allow the sheet to bulge and thus caulk the joint.

Weight of Seams

It is difficult to get an accurate figure on the weight of seams since most tanks are incorporated in new designs. However, the type of seam shown in Fig. 4 was used on two tanks of different capacity which were built into structures without any change in the original designs. The actual increase in weight of the original item due to the integral tank was 42 lbs. for a 500 gal. tank and 32½ lbs. for a 150 gal. tank. This makes the increased weight per gallon for the 500 gallon tank 0.083 lbs. per gal. and for the 150 gal. tank 0.217 lbs. per gal. It is clearly seen that the larger the capacity of the tank the greater weight saving accomplished. This is entirely the reverse of the increase in weight due to the separate type of tank since in the latter case the weight of the tank increases with the capacity. In "Technical Aerodynamics" by Wood [4] a plot is given for the weight of dural tanks. From this curve, the weight of a 150 gal. tank is 70 lbs. and for a 500 gal. tank 190 lbs. or 0.466 lbs. per gal. and 0.38 lbs. per gal. respectively. These figures may vary with type of design but they are a good average. Due to lack of sufficient data, curves for the weight of integral tanks cannot be accurately plotted. A fairly good estimate taken from comparisons of weights of different installations shows that for tanks having a capacity of 100 to 300 gals. the weight is 0.32 to 0.18 lbs. per gal. and for tanks having a capacity of 500 to 1000 gals. 0.10 to 0.06 lbs. per gal.

Testing the Tanks

Testing for leaks in the built-in tank is a rather difficult task. Each individual manufacturer will find his own means according to the type of construction used and the locality in which the tank is placed. A few general suggestions are offered.

In wing tank testing, the tank should be tested before the bottom or final cover is put on, any leaks being repaired at that time. The tank is tested again after the final cover is put on the tank, but before any other part of the wing adjacent to the tank is covered, *i.e.*, the tank should be completed and tested before the adjacent structure is covered. Hulls, fuselages or floats do not offer as difficult problem as wings.

The most commonly used method of testing is to fill the tank with water and test under a pressure not exceeding 3½ lbs. per sq. in. This method offers some difficulty in that the tank must be thoroughly dried afterwards. Circulating hot air not exceeding 88°F. through the tank will promote quick drying. Air that is too hot is detrimental to the properties of aluminum alloy and should be avoided.

Another and preferable method of testing the tank is to fill it with light machine oil to approximately ⅓ or ¾ the depth of the tank and then apply air pressure (3½ lbs. per sq. in.) through pump connections or filler openings.

Where a leak develops, the following procedure should be used to tighten the joints:

(1) Inspect all rivets to be sure that they are properly headed and driven.

(2) For a distance of 3–6 inches on either side of the leak tighten all rivets, working toward the faulty portion from both sides.

(3) Apply a light coat of the sealing medium along the seam, externally as well as internally if possible, and allow this to thoroughly dry before testing the tank again. The sealant may be sprayed, painted or perhaps applied with an ordinary oil can.

The fact that the tank has to be periodically examined for leaks necessitates inspection holes in the structure adjacent to the tank. These should be large enough to allow sufficient room for repairs and manipulation of tools and sufficiently reinforced.

In repairing tanks that have already been filled with gasoline, care should be taken that personnel working in or adjacent to the tanks are equipped with an approved type of mask to prevent asphyxiation or poisoning from gas fumes. All tanks should be flooded with water to float out gas and then thoroughly ventilated by blowing in air before allowing anyone to work upon them. An attendant should be on hand to assist anyone working upon the tank who may be overcome.

The structure adjacent to the tank should be well ventilated to carry away fumes and gases which may occur. This is especially true where tanks are in close proximity to the passenger compartment or engines. The space allowed for ventilation will also permit the tank to "breathe", *i.e.*, expand or contract with changes of atmospheric pressure. In the Martin Clipper ships, the hull tanks are well ventilated by allowing a space between the top of the tanks and the cabin flooring. Air is circulated through this space entering from the cabin proper, sweeping across the top of the tank and out through exhaust ducts at the side of the ship.

Fuel line connections can be made at the side or tops of tanks as suits the construction. Strainers or foot valves should be provided and located in a place convenient for cleaning.

Cleaning the Tank

Tanks can be cleaned with Benzol as described previously or rinsed with a 5% potassium dichromate solution. In connection with cleaning out water after testing, the following should be noted: No known commercial or aviation gasoline appears of itself to

[4] Karl D. Wood, *Technical Aerodynamics*, McGraw-Hill Book Company, 1935.

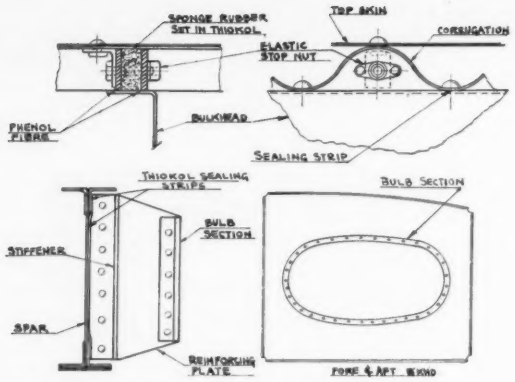

FIG. 7.

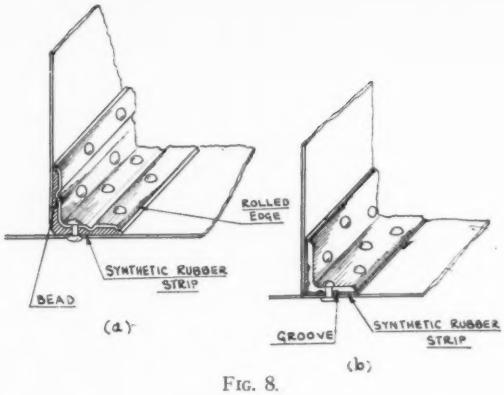

FIG. 8.

corrode aluminum, however, the presence of water in gasoline appears to cause electrolytic corrosion of aluminum due to: (1) Combination with heavy metal particles accidentally introduced into the tank. (2) Heavy metals in the gasoline (such as is in tetra-ethyl fluid. (3) Water may be introduced into the tank during filling; by evaporation and condensation due to abrupt changes in temperature and pressure; or by accidentally leaving inlets open. To prevent any electrolytic forms of attack that may occur, an "Alclad" type of material should be used for the tank compartment. Oxide coatings, especially those formed by boiling in dichromate solutions, may be desirable. In some cases, a capsule containing the dichromate may be placed at a low point in the tank, where it can be renewed at periodic overhauls.

Further experimental work on seams and materials for sealing is suggested. The resultant saving in weight and space should amply repay for expenditures involved. It is suggested that some work be done on the two types of seams shown in Fig. 8. Type (a) is formed from sheet and has a bead rolled into the flange. The joint should be sealed with either "Thiokol" or "Du Prene" with a corresponding cement between faying surfaces. When the rivet is driven, it should form a tight yet flexible seam by squeezing the sealing strips. The rolled edge keeps the sealant from spreading outward from the seam. Fig. 8 (b) is an extruded angle having a series of grooves cut in the flanges of the angle. The angle should also be used with a form of synthetic rubber. When riveted together, it provides a series of sealing edges; the sealant being squeezed together and forced up into the grooves when the rivet is tightened.

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Sound-Proofing Propeller Test Houses

RAYCROFT WALSH and EDWIN D. EATON, *Hamilton Standard Propellers*

(Received November 14, 1936)

Part I

The Noise Problem Created by Propeller Testing

PART I of this paper presents a résumé of the noise problem created by propeller testing and discusses in general terms the steps taken to arrive at a solution. The methods used to eliminate these complaints are discussed in Part II of this paper which gives the comparative results obtained with two methods of sound-proofing propeller test houses.

The problem created by the numerous and sometimes violent complaints caused by noisy propeller tests was such that no company valuing its good will could afford to ignore it. Hospitals, chambers of commerce, police departments, and other civic bodies, as well as individuals, all raised their voices in protest. One might wonder why propeller testing was done in a populated area from which complaints might arise, but it should be pointed out that noise of great intensity will travel for many miles and may be cause for complaint as far as twenty-five miles from its source.

The problem was further complicated by the fact that the investment represented by the large number of existing test houses of standard design and brick construction was so great that the solution arrived at had to be applicable to these houses at a reasonable cost per unit. It was known that two or three test houses had been silenced abroad, but these houses had been initially designed with this objective in mind and had been constructed at great expense.

It has been said that high speed propeller tests are the source of the most intense, continuous sound ever created by man. Constant noise of only moderate volume is sometimes more objectionable than occasionally occurring noise of much greater volume. On certain days, the intensity of the noise as far away as four miles from the source of the test may be equivalent to the noise in an interurban train or to that of a police whistle at a fifteen-foot distance. A steady uninterrupted noise of this intensity affects the hearing and may also have detrimental effects on nervous and mental conditions.

Irrespective of how noisy tests have been, only one or two complaints have been received with reference to the noise during the daytime when there was either a clear sky or broken clouds at high altitudes. These complaints were generally of a mild nature and usually came from people living within a few hundred yards of the test houses. Only occasionally were complaints received during nights which were clear and these also were of local origin.

Noisy tests on days or nights when there was a continuous unbroken cloud ceiling, either at high or low altitude, almost invariably caused complaints. The number of these complaints sometimes averaged about eight or ten an hour and were received from all points of the compass.

Unfortunately, it was impractical to keep a record of the actual number of complaints received during noisy tests, nor on the direction from which complaints originated under various conditions of cloud level, or ceiling, and wind direction. However, it is known that both ceiling and wind direction do have a marked effect on the transmission of sound through air. On days when there was a strong wind blowing, the majority of complaints were received from a direction "down-wind" from the test. A low ceiling of clouds reflects noise, because at times when a noisy test was being run, the majority of the complaints might come from a considerable distance and practically no complaints from the immediate vicinity of the test. It is believed that with such a low cloud ceiling, noise is reflected back and forth between the ground and the clouds and is thereby transmitted great distances. Thus it is possible for the noise to be heard a great distance and not heard at some place comparatively close to the source of the noise.

During the latter part of December, 1933, an important test of military nature was being run one night when there was a very low ceiling of clouds and a heavy snow was falling. It was part of this test to change the pitch of the propeller periodically with a resulting change in the intensity and frequency of the noise emitted by the propeller. To all intents and purposes, the effect was that of an airplane flying around in the snowstorm hunting for a place to land. People in towns as distant as twenty-five miles from the test called their local airports inquiring as to whether an airplane was lost in the storm and was seeking the airport. This belief on the part of many people was strengthened by the changing of the propeller pitch which gave the effect of the airplane occasionally going away only to return again. On the night that this test was being run, there was no wind blowing and the low ceiling of clouds reflected the noise equally in

all directions. This particular test was the worst offender of any that have been run, and it is estimated that several hundred telephone calls were received at the offices of the two local newspapers during the course of the evening.

In order to reduce complaints to a minimum, it was decided to limit all noisy tests to the period between eight o'clock in the morning and four-thirty o'clock in the afternoon. It was also decided to discontinue all very noisy tests on days when there was an unfavorable ceiling such as either high or low unbroken clouds. After this program of curtailed hours of operation was put into effect, there was a very marked reduction in the number of complaints received.

However, this curtailment of hours placed a severe handicap on the propeller test program and early in 1935 it was decided to extend the operating time of propeller tests to seven o'clock in the evening. This extension, together with the fact that test requirements had been steadily increasing with a corresponding increase in test noise, again brought in a great number of complaints.

At this point, it was decided to completely and fully investigate the problem of test house silencing. Well known sound-proofing experts were contacted. Investigation continued through the early part of the Summer of 1935, and it was decided to install a temporary sound-proofing structure in one of the propeller test houses. This type of sound-proofing is described in Part II of this paper as the "blanket type" of sound-proofing.

The results obtained with this first experimental sound-proofing were very gratifying and it was found possible to conduct noisy tests in this test house under all but the most unfavorable of weather conditions. In order to obtain comparative data, arrangements were made to shut down all production engine testing at the Pratt & Whitney Aircraft plant on two consecutive Sunday mornings and to run a very noisy propeller test in two test houses which were identical except for the fact that one had been supplied with the blanket type of sound-proofing and the other had no sound-proofing. A full-size propeller, running at a tip speed of 1220 ft. per sec., was used in the test. The test was made in the unsoundproofed house first and the resultant noise, despite very *favorable* weather conditions, was so great that local Public Prosecutor and a policeman soon appeared at the test house demanding that the test be stopped. A deluge of protests were also being received by telephone. The next Sunday the test was repeated in the sound-proofed test house under very *adverse* weather conditions. The test was run for a period of three or four hours on Easter Sunday morning without a single complaint being received.

A few months after this first trial installation was completed, work was begun on an entirely different and more easily handled type of sound-proofing in another of the propeller test houses. The results obtained with this second or "tile" type of sound-proofing are likewise included in Part II of this paper. It should be pointed out here that the method and arrangement of these two highly satisfactory methods of sound-proofing were worked out almost in their entirety by our own engineering personnel using commercially available sound-absorbing materials.

From its inception the whole sound-proofing program was laid out so that a maximum amount of information could be obtained. The first installation consisted of installing all the sound-absorbing material in the main body of the test chamber itself. The second step consisted of placing the material in the intake and exhaust flues as well as in the body of the test chamber. A third step in the sound-proofing program has just been completed in which all the sound-proofing material was placed in the flues. This step-by-step procedure has allowed us to determine the most efficient type of installation from the standpoint of noise reduction as well as the most economical method of accomplishing the desired results.

It is our ultimate aim to be able to operate our tests twenty-four hours a day, regardless of weather conditions, without causing anyone concern due to noise. The author's organization has endeavored to pass on the information which it has obtained to the Army and Navy as well as several aeronautical concerns, some of whom have evolved very satisfactory types of sound-proofing patterned after these pioneering installations.

Part II

Summary

Sound measurements, recording both noise level and predominate frequencies, were made with a full size two-bladed propeller running at a tip speed of 1220 ft. per sec. in a test house which was not sound-proofed, a test house in which there was a blanket type of sound-proofing structure, and in a test house which had a tile type of sound-proofing treatment. Measurements were made at eight arbitrary stations located in and about the test houses and at distances up to one mile from the test houses. Readings were taken at these stations in both winter and summer when no tests were being run and serve as a comparison for the readings obtained when the noise tests were being run.

The test results obtained with the two methods of sound-proofing indicate that both methods are nearly equally satisfactory from the standpoint of noise reduction for normal daytime propeller testing. The test results further indicate that the blanket type of sound-proofing resulted in a slightly lower noise level in the test operator's room than did the tile type of sound-

proofing; but from other standpoints, such as permanency of installation, accessibility to engine and propeller, diameter limitation, etc., the tile sound-proofing method was definitely superior.

The majority of the observed data is presented in the form of tables which show the noise level in decibels as well as the relative frequency magnitude in millivolts of the predominating frequencies at each of the several stations.

Introduction

The recent tendency towards propellers of large diameter and the requirements for overspeed testing, both of which have resulted in high propeller tip speeds, has made the problem of noise from propeller testing a serious one.

The noise created from a propeller, whose tip speed approaches or surpasses the speed of sound in air, is terrific and may be heard over great distances with such intensity that any prolonged operation under these conditions is impossible. Particularly is this so when the weather is bad and there is a "low ceiling".

In order that high speed propeller tests could be run at all, and particularly in bad weather, it was obvious that is was necessary to reduce the intensity of the sound being emitted from the test house to a point where it only slightly raised the noise level in any given vicinity.

Of the several possible means of accomplishing this result, two entirely different and distinct methods were decided upon. One method was an attempt to absorb the noise at its source, *i.e.*, the propeller tips, by enclosing the propeller in a tunnel of sound-absorbing material. This method is referred to in this paper as the blanket sound-proofing. The other method consisted of lining the walls and ceiling of a test house with a sound-absorbing tile and installing baffles and "ribbon walls" made of this title in the intake and exhaust flues of the test house. This second method is called the tile sound-proofing. Each of these two sound-proofing methods were installed in different test houses which were of identical size and construction but were "back-to-back" and had the same center-line.

Apparatus

The two test houses used in making the sound-proofing installations were located in East Hartford, Connecticut, at the plant of the Hamilton Standard Propellers Division of the United Aircraft Corporation. Fig. 1 shows one of these test houses before any sound-proofing was installed and Fig. 2 shows this test house after the tile sound-proofing was installed. Fig. 3 shows the test house with the blanket sound-proofing.

The propeller used in making all the sound tests was a Hamilton Standard Constant Speed Propeller, Hub Model 12D40 and Blade Design 6127A–3. The diameter of this propeller was 10 ft. 6 in.; all measurements were made with a constant tip speed of 1220 ft. per sec. at which speed the propeller absorbed 500 b. hp. The engine used for all tests was a Pratt and Whitney direct drive Hornet R–1690 engine No. 1856.

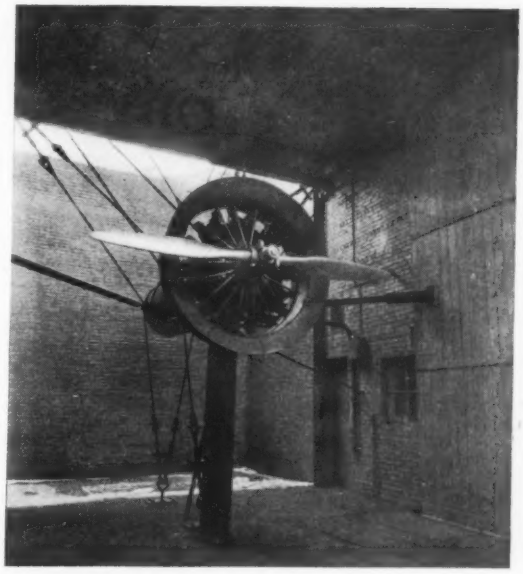

Fig. 1. View showing rear of 18 foot propeller test house with no sound proofing in place.

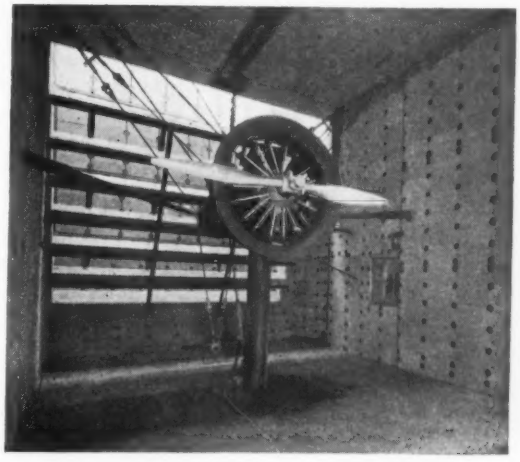

Fig. 2. Rear view of tile treated test house showing baffles and ribbon walls in rear flue.

The equipment used in making the sound measurements consisted of a General Electric Audio Noise Meter, Catalog No. 3658794G1, Serial No. 712430, and a General Radio Wave Analyzer, Type No. 636–A, Serial No. 290. Throughout the tests, the calibration of the wave analyzer was held constant so that 53.5 decibels at a frequency of 1000 cycles per second was equivalent to a scale deflection on the wave analyzer of 45 millivolts.

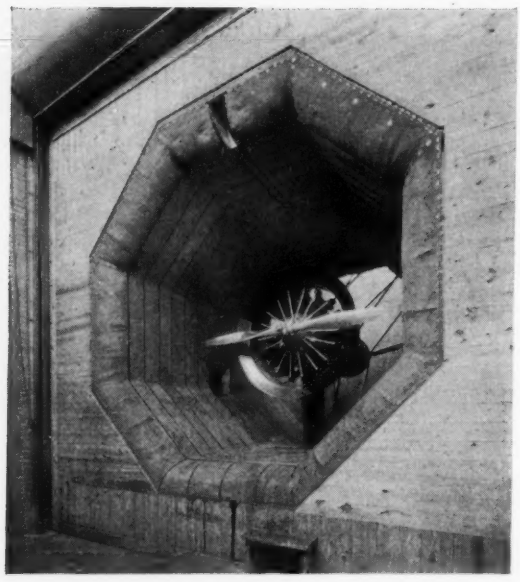

FIG. 3. Front view of temporary sound proofing structure in propeller test house showing observation tunnel and rear baffle.

TESTS

Following is a list of the stations where sound measurements were made and their location with respect to the test houses:

Station 1—Located in the test operator's room at a point midway between the instrument and control desks of the two test houses.

Station 2—Located directly in front of and about six feet away from the large double doors leading into the front of the test chamber.

Station 3—Located just outside the building in the plane of rotation of the propeller.

Station 4—Approximately 200 yards due North of the test houses.

Station 5—Approximately 1800 yards due South of the test houses.

Station 6—Approximately 1250 yards due North of the test houses.

Station 7—Approximately 1500 yards due West of the test houses.

Station 8—Approximately 1150 yards due East of the test houses.

The data taken can be divided into four groups. Group I was made when no tests were running and indicates the general noise level at the several stations in both winter (snow on ground) and summer. Frequencies were not measured as there were none of a predominating nature. Group II indicates the noise level and frequency at the several stations with no sound-proofing. Groups III and IV indicate the results obtained with the blanket and tile sound-proofing, respectively.

RESULTS AND DISCUSSIONS

GROUP I (No tests running)

Station No.	Noise Level in db. Winter	Noise Level in db. Summer
1	27	30
2	27	30
3	22	32
4	20	33
5	20	33
6	23	37
7	24	33
8	29	34

These readings will serve to give a general picture of the noise level at the several stations when no tests were being run. The difference in these two sets of readings can readily be explained by the fact that the readings made in the winter were made on a day when there was over a foot of snow on the ground and it is well known that sound is absorbed by loose snow and does not travel as far nor seem as loud as it would over relatively much harder ground.

GROUP II (No sound-proofing)

Station No.	1	2	3	4	5	6	7	8
Noise Level in db.	103	105	89	81	60	55	40	60
Frequency in c.p.s.	Relative Frequency Magnitude in mv.							
28	60	120	....	10	8	..	3	16
37	70	100	1300	25	10	5	2	20
56	90	140	....	..	..	..	..	..
62	70	90	40	..	..	..	..	..
74	1800	2000	400	160	10	8	5	25
84	....	....	100	12	..	..	..	..
148	150	225	500	40	16	8	2	4
168	300	1000	....	20	..	..	..	..
222	800	2500	1500	160	60	12	2	20
296	850	1600	1000	400	..	..	..	..
370	800	1600	900	300	..	..	..	..
444	2000	1400	1500	600	..	..	..	..
518	800	1400	1200	400	..	..	..	..

It will be noted from this table that the noise level at the nearby stations was tremendous before any sound-proofing was installed and that at the more distant stations, the noise level was increased as much as 40 db. over the noise level present when the test was not being run. It should be noted here that the measurements of this group were made in the winter when there was snow on the ground and for that reason are comparable to the measurements of Group I which were made in the winter.

GROUP III (Blanket Sound-Proofing)

Station No.	1	2	3	4	5	6	7	8
Noise Level in db.	87	100	88	67	29	32	28	32
Frequency in c.p.s.	Relative Frequency Magnitude in mv.							
28	30	60	....	....	....	....	....	..
37	80	120	1000	16	....	....	....	..
56	....	....	....	....	....	....	....	..
62	70	....	40	....	....	....	....	..
74	1200	1600	300	80	1.5	0.25	1.5	2
84	....	....	60	6	....	....	....	..
148	400	200	400	35	0.5	1	1	1
168	600	160	....	5	....	....	....	..
222	450	1400	1200	80	4	0.5	0.5	3
296	800	1600	800	125	....	....	....	..
370	300	1800	600	60	....	....	....	..
444	400	800	1350	100	....	....	....	..
518	400	500	300	90	....	....	....	..

Group IV (Tile Sound-Proofing)

Station No.	1	2	3	4	5	6	7	8
Noise Level in db.	91	102	87	68	35	31	32	41
Frequency in c.p.s.	Relative Frequency Magnitude in mv.							
28	45	60	....	....	....	....	....	..
37	30	80	250	20	0.8	1	1	6
56	....	....	....	....	....	....	....	..
62	....	....	....	....	....	....	....	..
74	1200	1200	1200	100	3	0.5	1.2	9
84	....	....	....	....	....	....	....	..
148	600	1600	800	60	0.5	0.75	0.8	3
168	160	80	100	10	....	....	....	..
222	700	800	1400	60	1.5	0.5	0.8	3
296	1200	1800	1500	160	....	....	....	..
370	350	1400	1000	45	....	....	....	..
444	1000	1400	600	120	....	....	....	..
518	300	1500	200	100	....	....	....	..

Referring to the frequency measurements of Group II, it is apparent that the fundamental frequency of the noise emitted by the two-bladed propeller was 2 × r.p.s. or 74 cycles per second. A second fundamental frequency present was due to engine cylinder explosions which, in this case for a nine-cylinder radial engine, would result in a frequency of 4.5 × r.p.s. or approximately 168 cycles per second. With the exception of the one frequency of 62 c.p.s., the source of which is unknown, all the other frequencies are some functions of the two aforementioned fundamental frequencies. No frequencies above 518 c.p.s. were recorded inasmuch as they were of extremely small magnitude.

Referring further to the frequency measurements, it will be seen that at Stations 1 and 2 the predominating frequencies are from 74 to 518 c.p.s.; while at Stations 3 and 4, both of which are outside but near the building, the predominating frequencies include the lower as well as the higher ones. At the more distant stations, it is apparent that the higher frequencies were damped out and it is interesting to note that the frequencies due to the engine explosions were entirely absent at the distant stations.

The measurements of Group III were made when there was snow on the ground and are, therefore, comparable to those of Group II. The noise levels in this table indicate that the blanket sound-proofing resulted in a material reduction of noise level in the operator's room and a reduction of as much as 31 lb. at one of the more distant stations.

At Stations 1 and 2, there is a marked reduction in frequencies 74, 168, 222, 444, and 518; while the majority of other frequencies showed either none or at best only a slight decrease over the frequency mag-

nitudes at these stations when there was no sound-proofing. At Stations 3 and 4, all frequencies showed a marked reduction and the only frequencies to carry to the more distant stations were those in the middle band, namely, 74, 148, and 222.

The measurements of Group IV were made in the summer when there was no snow on the ground and on a very cloudy day when there was a "low ceiling". From the standpoint of noise, these measurements were made under the most adverse weather conditions, whereas Groups II and III were made on clear days when there was snow on the ground. In spite of this unfavorable comparison, it will be noted that although the reduction of noise level in the test operator's room was not as great as with the blanket sound-proofing, there was still a reduction at the more distant stations of as much as 25 db. over the noise level present with no sound-proofing.

This table shows that for Stations 1 and 2, the low frequencies are of less magnitude than the same frequencies in Group III but the higher frequencies at these stations are of greater magnitude than those of Group III. At Stations 3 and 4, only the very low and very high frequencies are less than with the blanket sound-proofing. Attention is called to frequency 74 which at Station 3 is 1200; while in Group III at this station, this frequency had a magnitude of only 300. At the more distant stations, all frequencies present in Group III were detected with the addition of frequency 37.

Résumé

The following tabulations sum up the noise level measurements of Groups II, III, and IV, and show the reduction in noise level in db. with both the blanket and tile sound-proofing over the measurements taken with no sound-proofing. These differences in noise level are also presented in terms of reduction in sound energy in per cent.

From these two tabulations, it is apparent that both sound-proofing methods reduce the noise from the propeller at the more distant stations to a point where it only slightly raised the noise level above that when no tests were being run. It will be noted that at these stations, the reduction in sound energy with but one exception is greater than 93%.

Station Number	Noise Level Group II	Noise Level Group III	Reduction in Noise Level Group III Over Group II	Reduction in Sound Energy Group III Over Group II
1.....	103 db.	87 db.	16 db.	97.49%
2.....	105 db.	100 db.	5 db.	68.40%
3.....	89 db.	88 db.	1 db.	20.60%
4.....	81 db.	67 db.	14 db.	96.20%
5.....	60 db.	29 db.	31 db.	99.91%
6.....	55 db.	32 db.	23 db.	94.99%
7.....	40 db.	28 db.	12 db.	93.69%
8.....	60 db.	32 db.	28 db.	99.84%

Station Number	Noise Level Group II	Noise Level Group IV	Reduction in Noise Level Group IV Over Group II	Reduction in Sound Energy Group IV Over Group II
1.....	103 db.	91 db.	12 db.	93.69%
2.....	105 db.	102 db.	3 db.	50.10%
3.....	89 db.	87 db.	2 db.	36.90%
4.....	81 db.	68 db.	13 db.	94.99%
5.....	60 db.	35 db.	25 db.	99.68%
6.....	55 db.	31 db.	24 db.	99.60%
7.....	40 db.	32 db.	8 db.	84.15%
8.....	60 db.	41 db.	19 db.	98.74%

Too much weight cannot be placed on a direct comparison of the noise level and frequency measurements made with the two methods of sound-proofing because of the extreme differences in weather and ground conditions when the readings for each group were made. However, it appears that the blanket sound-proofing is slightly more efficient at the lower frequencies than is the tile sound-proofing; although it is believed that the measurements obtained with the tile sound-proofing would have been considerably lower had they been made under as favorable weather and ground conditions as were the measurements made with the blanket sound-proofing.

Conclusions

(1) Both methods of sound-proofing are equally satisfactory from the standpoint of noise reduction for normal daytime propeller testing.

(2) The blanket sound-proofing resulted in a slightly lower noise level in the test operator's room than did the tile sound-proofing.

(3) Neither method resulted in adverse engine cooling.

(4) The tile sound-proofing appears to be definitely superior to the blanket sound-proofing from the standpoint of permanency, accessibility for mounting engine and propeller, ease of cleaning, ease of making repairs, and fire hazard.

(5) The blanket sound-proofing provides a definite limit to propeller diameter and prevents a full view of engine and propeller; whereas the tile sound-proofing does not materially reduce the size of the test chamber and does not obstruct the view of the engine and propeller.

The Next Five Years in Spark-Ignition Aviation Engines

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(Received December 4, 1936)

Weight per Horsepower

THE author sees no reason to believe that the trend towards lower weight per horsepower, which has been evident throughout the history of the industry, will not be continued during the next five years. Considering the possibilities, it is useful to recall that geometrically similar cylinders will run under similar conditions of volumetric efficiency, stress, vibration, etc. if piston speed is kept constant[1]. This means that cylinders of widely different sizes should be able to run at the same piston speed and mean effective pressure, provided the designs are approximately similar.

Table 1 shows the present maximum-power ratings of several modern airplane engines, together with the corresponding mean effective pressures and piston speeds. If the maximum figure for the two latter quantities is taken as the limiting value for the near future, it is interesting to see, in Table 2, the results in terms of output, and weight per horsepower, for the engines in question. In view of the wide divergence in design, it is rather surprising to see how little difference there is in the weight per horsepower of these engines, assuming that they are run at the same piston speed and brake mean effective pressure.

Table 2 is based on mean pressures and piston speeds at present attainable. Further reduction in weight per horsepower should be possible as improvements in fuels, cooling, and structural design make higher mean effective pressures and higher piston speeds possible. There is reason to believe that such improvements will continue during the next five years, though the results in terms of weight per horsepower are bound to follow the law of diminishing returns.

[1] E. S. Taylor, *Design Limitations of Aircraft Engines*, Aero Digest, January, 1935.

Number of Cylinders

Again recalling the principles of similitude, the weight of geometrically similar cylinders will be proportional to the cube of the dimension, while the power output at constant piston speed will be proportional to the square of the dimension. This means that the

Table 2

Possible Power and Power-weight Ratios for Several Airplane Engines

b.m.e.p. = 198
Piston speed = 3370

Engine	hp.	r.p.m.	Wgt. lb.	lb. per hp.
Wright Cyclone 9 cyl.	1350	2940	1163	.860
P. & W. Twin Wasp 14 cyl.	1690	3670	1265	.748
Wright Super-Conqueror 12 cyl.	1280	3240	1000	.781
Bristol Pegasus 9 cyl.	1190	2700	995	.837
Napier Dagger 24 cyl.	1385	5400	1280	.925
Rolls-Royce Kestrel 12 cyl.	1190	3670	918	.770
Gnome-Rhone 14 cyl.	1830	3100	1260	.688
Hispano Suiza 12 cyl.	1650	3020	1000	.605

Table 1

Maximum Ratings and Other Data on Several Airplane Engines — 1936

Engine	Bore in.	Stroke in.	Displ. in.³	Wgt. lb.	Max. Rated hp.	R.p.m.	Piston Speed ft./min.	B.m.e.p. lb./in.²	Weight, lb./hp.
Wright Cyclone	6⅛	7⅛	1,820	1,163	1,000	2,200	2,520	198	1.16
P. & W. Twin Wasp	5½	5½	1,830	1,265	1,000	2,600	2,380	166	1.27
Wright Super-Conqueror	5.13	6.25	1,587	1,000	675	2,450	2,550	138	1.48
Bristol Pegasus	5¾	7½	1,753	995	1,000	2,700	3,370	167	.995
Napier Dagger	3.81	3.75	1,025	1,280	760	3,500	2,190	167	1.68
Rolls-Royce Kestrel	5.00	5.50	1,300	918	695	2,900	2,660	146	1.32
Gnome-Rhone 14K	5.75	6.50	2,300	1,260	1,100	2,400	2,600	154	1.14
Hispano Suiza 12Y	5.9	6.69	2,190	1,000	880	2,400	2,680	133	1.14

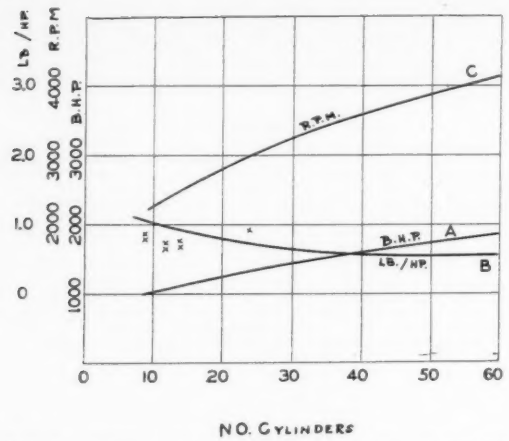

FIG. 1. Power, r.p.m. and weight per hp. of engines with similar cylinders. Displacement of each engine 1820 cu. in., piston speed 2520 ft./min., b.m.e.p. 198 lbs./sq. in., weight—1060 lb. each. x = weight per hp. from Table 2.

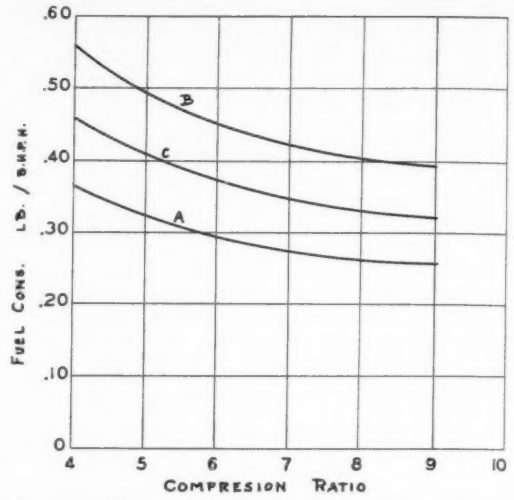

FIG. 2. Specific fuel consumption at various compression ratios. A. Theoretical cycle, fuel-air ratio .067. B. Present best airline consumption. C. Estimated airline consumption within five years.

weight per horsepower of similar cylinders should vary inversely with the dimension, and engines having many cylinders theoretically should have a weight advantage over engines of equal displacement having fewer cylinders.

Fig. 1 is of interest in this connection. It is based on a 9 cylinder, 1000 hp. engine of 1820 cubic inches, running at a piston speed of 2520 ft. per min. and a b.m.e.p. of 198 lbs. per sq.in. Retaining the same piston speed and mean effective pressure and increasing the number of cylinders increases the power, as shown by curve *A*. If the weight of such a series of engines remains proportional to the displacement, the weight per horsepower would decrease in accordance with curve *B*. To maintain a constant piston speed, the r.p.m. would rise, as shown by curve *C*.

In actual practice, however, geometric similitude cannot be achieved. As the size of cylinders decreases, the thickness of sections cannot always be reduced proportionately, and as the number of cylinders is increased, the form of the engine may become complicated, the accessories heavy, and the theoretical weight advantage of a multiplicity of small cylinders may be lost. This trend can be noted from the specific weights given in Table 2, and plotted as x's in Fig. 1. Based on the particular engines chosen, the number of cylinders giving lowest weight per horse-power is in the neighborhood of twelve, but owing to the wide departure from similitude in design, this should not be taken too seriously. It will be interesting to see if, as the development of the engines of Table 2 proceeds, the relative positions with respect to weight per horsepower, as indicated in Table 2, are maintained.

Fuel Consumption

Next to great reliability and high ratio of power to weight, low specific fuel consumption at cruising speed seems to be the most important characteristic of airplane engines, at least for airline and military service. Curve *A* of Fig. 2 shows the maximum theoretical fuel consumptions attainable with normal gasoline-air mixtures (ratio of gasoline to air .067) at various compression ratios, and curve *B* shows the fuel consumptions obtained in airline operation at the present time. The difference between these two curves is due to the following factors: (a) Time required for combustion. (b) Direct heat losses. (c) Incomplete mixing of fuel and air. (d) Friction and pumping. (e) Leakage. (f) Excess fuel necessary to control detonation, cooling and to compensate for poor distribution.

If it is assumed that the irreducible minimum of friction and pumping loss is 10%, direct heat loss 5% and combined losses due to combustion time, mixing distribution and leakage 5%, a "corrected value" of the theoretical fuel consumption (amounting to .38 lb./b.hp. hr. at compression ratio 6) can be plotted on Fig. 2 (curve *C*). The difference between curves *B* and *C* represents the possibility for improvement, provided the assumption as to the irreducible losses are correct. Most of this possible gain can be achieved by improving engines and fuels to the point where operation on the "best economy" mixture (about .063 gasoline-air) is possible without detonation or overheating, and by providing checks and controls to hold the fuel-air ratio at that point. The author predicts that cruising fuel consumption in service for Otto-cycle aircraft engines will fall to .35 or less within the next five years.

Cooling

It must be admitted that air-cooling has tremendous advantages in respect to light weight, mechanical simplicity, and reliability. For these reasons air-cooling will continue to be used for many purposes over the

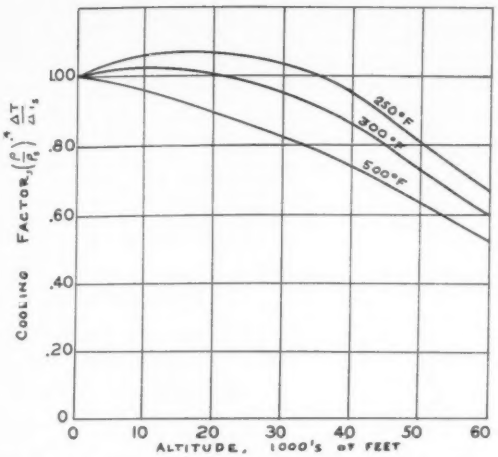

FIG. 3. Cooling factor for three different cooling-surface temperatures.

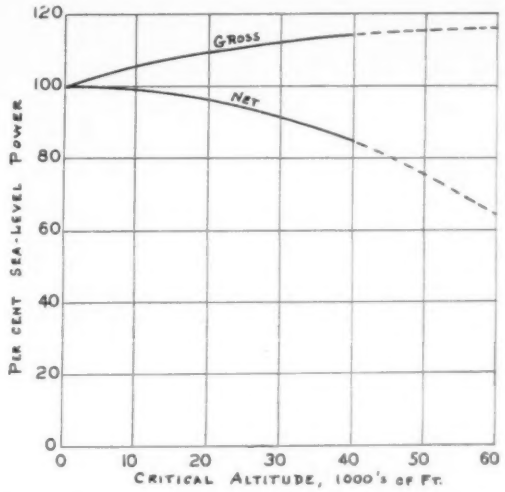

FIG. 4. Power of engines with gear-driven centrifugal superchargers at various altitudes. (From N.A.C.A. Technical Report 384)

next five years. On the other hand, air-cooling involves two serious limitations which may stimulate the development of liquid-cooled engines for certain fields of application.

The first fundamental disadvantage of air-cooling is that some power must be expended, either in the form of drag or blower power, to force the air through the cylinder finning. In a recent article on the future transport airplane[2], the following figures on power distribution are given for the near-future transport airplane:

Propeller losses	300 hp.	14%
Wing drag (total)	800 hp.	37%
Fuselage and tail drag	600 hp.	28%
Power plant drag and cooling	460 hp.	21%
Totals	2160 hp.	100%

It seems apparent that the last item presents attractive possibilities of reduction. In view of the refinement in present cooling systems for air-cooled radials, on which the above figures were based, it appears that for further improvements it may be necessary to resort to entirely-enclosed liquid-cooled engines of small frontal area, with wing-surface radiators. It would seem that with present metal wing construction, the wing surfaces can be adapted to act as radiating surfaces with very little increase in weight and complication. Booster radiators for climbing may be necessary. These considerations lead the author to predict the development of compact, liquid-cooled engines in the high-power ranges within the next five years.

The second fundamental disadvantage of the air-cooled engine has to do with flying at high altitudes supercharged to nearly sea-level power. If constant engine power is assumed, the airplane speed will be roughly proportional to the inverse square root of the density. Heat transfer per unit area will be roughly proportional to the product of the density times the velocity raised to the eight-tenths power and the temperature difference between the air and the radiating surface. Combining these two considerations, a "cooling factor", proportional to the four-tenths power of the density times the average temperature difference, can be derived. Fig. 3 shows this cooling factor as a function of altitude for three assumed radiating surface temperatures. Both on account of the high temperature of the hotter portions of the cylinders, and because of the difficulty of extending the fin area, the air-cooled engine is at a distinct disadvantage at the higher altitudes. On the other hand, liquid-cooling can be extended simply by increasing the radiator surface. This would indicate that for stratosphere flying, when and if it arrives, liquid-cooled engines are likely to be used.

SUPERCHARGING

In view of a probable increase in service altitudes, it is interesting to consider the problem of supercharging to high critical altitudes. Fig. 4 shows the estimated performance of airplane engines equipped with gear-driven centrifugal superchargers[3], designed for various critical altitudes. The curve assumes inter-cooling to 70° F., supercharger efficiency of 70% and that in each case the supercharger is designed particularly for the critical altitude in question. The serious falling-off in net engine power above 40,000 feet is quite evident. This decrease would be more rapid with lesser amounts of inter-cooling.

The possible alternatives to gear drive for the supercharger appear to be: (a) driving by a separate power plant; and (b) driving by exhaust-gas turbine.

[2] J. C. Hunsaker and G. J. Mead, *Around the Corner in Aviation*, Technology Review, December, 1936.

[3] See N.A.C.A. Technical Report No. 384.

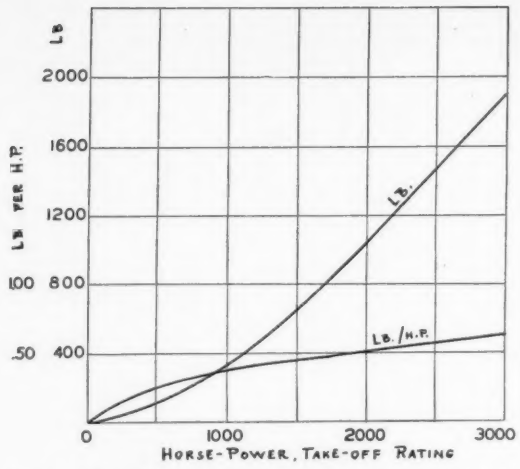

FIG. 5. Propeller weight *vs.* engine hp. for three-blade propellers. Constant forward speed and constant altitude. Weight, lb. $= 360\ (\text{hp.}/1000)^{1.5}$ and weight/hp. $= .36(\text{hp.}/1000)^{\frac{1}{2}}$

There seems to be little to be gained by driving superchargers separately. The engine weight required will be approximately the same whether separate drive, or drive by the propelling engines is used, and failure of the auxiliary engines would effect all the propelling engines together. For the "future" airplane, referred to previously, having 2160 rated horsepower, the power required for supercharging to sea-level pressure and temperature would be 570 hp. at 40,000 feet and 1080 hp. at 60,000 feet. The weight involved would seem prohibitive either with separate drive or drive by sufficiently large propelling engines.

The most attractive alternative is, of course, the exhaust-turbine drive. It is difficult to predict what can be achieved with this type of installation on account of the meager information available on exhaust turbine efficiencies under high altitude conditions. Most estimates of exhaust-turbine supercharging have been based on the simple assumption that with sea-level pressure at the engine exhaust, sea-level pressure can be maintained at the engine intake. Such an assumption would give a curve of constant horsepower vs. altitude and would give an ideal "solution" to the problem. Service tests of actual equipment, however, indicate that sea-level power has not been maintained at high altitudes. It seems safe to predict that the next five years will see the active development of the turbine-driven supercharger, and the use of installations of this kind for high-altitude work, provided it proves superior to the direct-driven type.

PROPELLERS

There seems no reason to predict any fundamental change in propeller design, at least for the next five years. The performance of modern controllable-pitch propellers approaches so nearly to theoretical possibilities that it is difficult to see how a great deal of improvement can be made over present designs. One serious problem is the weight of the propeller for large engines. Fig. 5 shows propeller weights plotted against engine horsepower for a given design, tip speed, and propeller efficiency, assuming the propeller weight proportional to the cube of the diameter. Evidently propeller weight is a serious problem in the case of high-power engines and the use of multiple-blade propellers, lighter blade materials, and more economical distribution of materials in propellers of a form essentially similar to those now in use may be anticipated.

The development and use of twin propellers turning in opposite directions may also be predicted, both for the purpose of reducing propeller weight and for reducing the torque-reaction in small, single-engine airplanes with high-powered engines.

With regard to stratosphere flying, the propeller seems to present one of the most difficult problems. In order to maintain good propeller efficiency with constant engine power, the propeller diameter should increase with increasing altitude, and the gear ratio should be progressively decreased in order to maintain constant tip speed. The mechanical difficulties here seem almost prohibitive, although one may expect to see much attention paid to the development of compromise propellers for high altitude flying within the next five years.

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Ice Formation in the Atmosphere

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(Received November 23, 1936)

A DISCUSSION of ice formation in the atmosphere must cover the changes of state from water vapor to condensed water in droplet formation and, finally, from water to clear ice, rime and frost. The fundamental phenomena involved are: (1), the condensation of water vapor in the atmosphere, (2), the existence of under-cooled water in the atmosphere, and (3), the freezing of under-cooled droplets. These will be discussed in this order.

The Condensation of Water Vapor in the Atmosphere

The natural processes by which portions of the atmosphere are cooled sufficiently to bring about condensation are: (1), cooling by mixing or through contact with a surface which itself has lost heat by radiation or is otherwise cooled; (2), spontaneous cooling by radiation; and (3), dynamical cooling by expansion.

Cooling by mixing or through contact with a cooled surface produces advective sea and land fogs.

Spontaneous cooling by radiation produces the fogs which are common on clear cool nights when the wind movement is light. This form of cooling, in conjunction with advectice effects, is also responsible for the stratus clouds so frequently formed at the base of subsidence or turbulence inversions. These clouds are common around the periphery of polar air masses and semi-permanent anticyclones.

Dynamical cooling by expansion is the most effective process of all. Such cooling may be due to the convective action resulting from the heating of surface layers, producing cumulus clouds; to the convective over-turning or the forcing aloft of warm air at the forward portion of the cold front type of discontinuity, producing cumulo-nimbus clouds; by the active upglide of warm moist air over the warm front, or by the lifting of cold moist air under the warm front due to the convergence of stream lines along the warm front, producing nimbus, stratus, or alto-stratus clouds. The lifting of moist air in crossing mountain ranges is also important in this respect—the cloud types produced depending on the stability of the air.

The cooling of portions of the atmosphere, by whatever process, will yield condensation only provided nuclei in sufficient numbers are present. Many investigations have been conducted in efforts to determine the exact nature of such nuclei. Recent discoveries have been made in this connection which prompt a radical revision of our ideas regarding the nature of these nuclei. It had formerly been believed that minute dust particles and ions of dissociated hygroscopic gases constituted the nuclei about which condensation takes place. It is true that condensation will take place about dust particles, provided other more effective nuclei are not available. The well-known Aitken's "dust counter" had, for years, been used to determine the number of nuclei available in different samples of air. It has developed, however, that the "dust particles" counted by this ingenious device are not dust at all, but other more effective nuclei. Indeed it has been demonstrated that no increase in the number of nuclei was observed in a sample of air that had been deliberately made dusty. It is now believed that the particles counted by the Aitken device are not dust, but other forms of nuclei. Hence it is quite probable that the ordinary dust of the air plays an unimportant rôle in condensation within the atmosphere.

It has been shown that a fourfold saturation is required before condensation will take place on negative ions, while a sixfold supersaturation is required for condensation about positive ions. This relative effectiveness of ions of opposite charge has been misunderstood by some, leading to an erroneous conclusion that negative ions could be regarded as nuclei of condensation for the atmosphere. But since there is no reason to believe that such a degree of supersaturation exists in the atmosphere, and which has never been recorded, it appears that such ions may be definitely eliminated from consideration here.

Hygroscopic nuclei from evaporating sea spray are, without doubt, carried into the air by turbulent and convective action. Also, more strongly hygroscopic nuclei are derived from the combustion of sulphur which is present in large quantities in coal and coke. Minute particles of sodium chloride have been shown to become deliquescent and form water droplets when exposed in air with a relative humidity as low as 75%. Other more strongly hygroscopic nuclei may result in condensation at still lower values of humidity. Table 1 (omitted) shows several examples of cloud formations existing at low humidities, that at Oklahoma City on April 6, 1935 being the most notable and indicating alto-cumulus clouds of 500 meters thickness in which the humidity ranged from 51% at the base to 54% at the top. Such observations certainly

suggest that the nuclei of condensation within the atmosphere consist of such hygroscopic material.

Köhler has conducted investigations concerning the nature of atmospheric nuclei wherein samples of cloud and cloud air have been analyzed. From such analyses he has not only provided interesting and valuable information about the size and number of nuclei of condensation, and the size and number of cloud droplets per unit volume, but he has rather definitely shown that the formation of cloud and fog droplets is dependent on nuclei of sodium chloride, magnesium chloride, and calcium sulphate, and, therefore, derived from sea spray. The acceptance of the proposition that nuclei of condensation do consist very largely of these materials, with their varying degrees of solubility in water, will contribute to an understanding of the capricious behavior of water in the liquid state at low temperatures.

Köhler's measurements of the size of cloud droplets show a range in the diameter from 0.011 mm. to 0.0638 mm., the average being 0.0276 mm. Many thousand such droplets could exist in each cubic centimeter, the number depending on the density of the cloud. Köhler has found that the water content of cloud (excluding water vapor) ranges from 0.12 grams per cubic meter in the less dense clouds to 1.84 grams per cubic meter in the most dense clouds. Conrad and Wegener have found maximum values approaching 5 grams per cubic meter. However, their values are based upon the assumption of 100% relative humidity in clouds and, in some cases, of conditions of supersaturation, whereas Köhler, in no case, found a relative humidity in clouds as high as 100%. His values varied from 92% to 97%, which are in close agreement with the values listed in Table 1 (omitted). The numerous cases shown in this table, wherein relative humidity values are considerably below 100% in clouds, show that it is decidedly unsafe to assume complete saturation in all clouds.

Initially, cloud droplets formed on nuclei of the same kind are uniform in size. Soon, however, due to different rates of condensation on the droplets in various portions of the cloud, a difference in size will result. Once this condition is established, due to the larger vapor pressure about the smaller droplets of greater convexity, these droplets will evaporate and the water therefrom condense on the larger droplets. Thus the larger droplets are continuously being formed at the expense of the smaller ones. Through such processes one may expect to find cloud droplets within the atmosphere through a wide range of sizes. Droplets less than 0.025 mm. in diameter are generally classified as cloud or mist. Larger droplets, ranging in size up to 5 mm., are found in various classes of rain. The larger drops, requiring for their support forces operating against the acceleration of gravity, are associated with strong vertical motions and are, therefore, confined to regions where these currents are produced. The smaller droplets, on the other hand, are found in clouds and fogs which are produced primarily by radiational cooling and hence may be expected in regions not associated with strong vertical currents.

The Existence of Under-Cooled Water in the Atmosphere

It has been a matter of common laboratory experience that water could be cooled far below its normal freezing point before solidification took place. Further, that as soon as the smallest particle of the substance in the more stable phase, (ice), is introduced, the under-cooled water is immediately transformed into it. The saturation vapor pressure over water in this under-cooled stage has a higher value than over ice at the same temperature. Thus when there is contact between this metastable phase and the stable phase, the vapor of the former will diffuse toward the latter and there sublimate. This process will continue until all the under-cooled water is converted to ice.

It is also well known that a slight agitation of under-cooled water will result in its almost immediate change to the solid state. Experimental researches have been conducted for the purpose of determining the tendency of under-cooled liquids to solidify by themselves, without the introduction of any crystallized particle. It has been found that microscopic crystalline nuclei make their appearance at different parts of the liquid and then grow until all the liquid has been solidified. It appears plausible that agitation, such as referred to above, might well assist in the arrangement of these crystalline nuclei, from which point the transformation is completed.

A very important consideration in connection with the existence of under-cooled water in the atmosphere is the fact that, since the salts of evaporating sea spray constitute the principle nuclei of condensation, each cloud droplet is in fact a salt solution. It is also well known that when a foreign substance is dissolved in a liquid, the freezing point of the solution is lower than that of the pure solvent. The solution will begin to freeze at that temperature where the vapor pressure of the solution and that of the pure solid solvent are the same. That is, where the solution is in equilibrium with the solid solvent. Only at this point can the two phases co-exist. Fig. 1 serves to illustrate this point.

The curve *A–B* shows the variation of vapor pressure of the solid solvent with temperature, while the curves *C–C′*, *D–D′* and *E–E′* represent vapor pressure variations with temperature of solutions of three different concentrations. The temperatures shown by the points *C*, *D*, and *E*, where the vapor pressures of the solutions and the solid solvent coincide, are the freezing points for the three solutions. This phenomenon may be understood by considering that

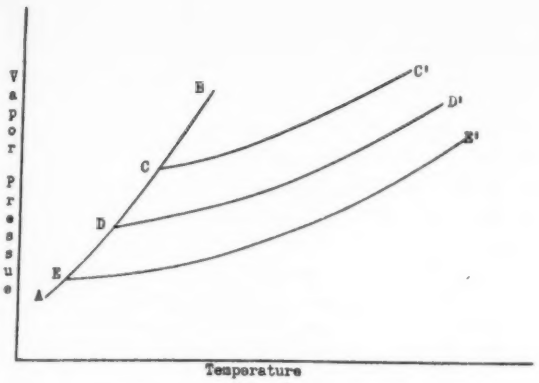

FIG. 1.

since the free surface of the solution must contain some molecules of the solute and therefore less molecules of the pure solvent, and since the vapor pressure of the solute is always less than the vapor pressure of the solvent, it may properly be expected that as more of the solute is added, lower vapor pressures will be measured for the solution and hence the freezing point will be lowered.

If P is the vapor pressure of the pure solvent, and P' that of the solution, then $P-P'/P=n/N$ where n is the number of gram molecules of the solute in N gram molecules of the solvent.

The molecular depression of the freezing point of water is 18.7° C. This rule, however, holds only for dilute solutions and it is probable that the extreme under-cooling of water is due in part to the presence of other substances in solution. Köhler has said: "The small amount of other salts than sodium chloride, for very concentrated solutions, plays a not unimportant rôle. The magnesium salts on account of their great hygroscopic characterstics and the calcium salts on account of their relatively small solubilities."

The lowest temperature recorded in Table 1 (omitted), at which ice was reported, was –22° C. Two observations of rime are shown in this table with temperatures as low as –26° C. and –28° C. Due to the difficulty of observing the formation of rime in small quantities, it may, at times, be confused with snow or ice crystals which already represent the crystalline state and do not show the existence of under-cooled water. L. T. Samuels, in his investigations of clear ice and rime deposits, found no temperature lower than –23° C. On the other hand many reliable observations have shown the existence of water in the liquid state at much lower temperatures. Köhler has reported cloud particles in liquid form at temperatures as low as –28° C. Wegener, in his Greenland travels of 1912-13, found water droplets at –34.5° C., and W. C. Haines has reported observing fogs at Little America at temperatures of –26° C., –30° C., and –44° C.

Several attempts have been made to explain the existence of under-cooled water in the atmosphere and some of these have attributed the phenomenon to the increased pressure resulting from the greater vapor pressure of very small droplets of greater convexity. It would require a pressure of about 150 atmospheres to lower the freezing point as much as 1 degree. This feature of increased pressure is, therefore, of little importance in accounting for the very low temperatures that have been observed. If, however, the demonstrated fact that salts of evaporated sea spray constitute the principle nuclei of condensation is accepted, a partial explanation of the existence of under-cooled droplets in the atmosphere can at least be provided. Köhler, in his paper "Zur Kondensation Des Wasserdampfes in der Atmosphäre" says: "The introduction of salt particles here makes it very clear that fluid water can and must exist in the atmosphere at very low temperatures". The full explanation seems to rest with the fact that the under-cooled droplet is not only a solution with the freezing point depressed on account of the addition of some foreign matter to the solvent, but also to the fact that the initial alignment of molecular aggregates, so necessary for solidification, is being delayed.

Process Involved in the Freezing of Under-Cooled Water on Aircraft

Pilots have reported three different kinds of ice deposits encountered in flight, *viz.*, clear ice, rime, and frost.

Clear ice is smooth and glassy in appearance, although when mixed with sleet or snow, may assume a rough appearance. It is very tenacious and has a tendency to form in a mushroom shape with its frontal area enlarged. It forms near the leading edge of the airfoil or strut and, due to the irregular shape into which it builds, results in a loss in lift and an increase in drag. It is much the most dangerous type of icing.

Rime is pure white, opaque, and granular in structure. It consists of tiny ice pellets which have little cohesion or adhesion. Rime builds into sharp-nosed deposits on leading edges and does not alter the form of the airfoil materially. Further, due to its granular structure, it is constantly being lost through vibration. This form of icing is seldom dangerous.

Frost is a light crystalline formation which never develops in such quantity as to become of much importance. It is the least dangerous of the three forms.

In order to demonstrate just what processes develop during the icing of aircraft, let it be assumed that there is water in liquid form, either as cloud, or, perhaps, falling rain, at a temperature of –8° C., which, from Table 1 (omitted), is noted to be within the average range of temperature for clear ice formation. Also, let it be assumed that the cloud particles encountered are of the average diameter of 0.03 mm. Each droplet then consists of 1.4×10^{-8} cc. As soon as the plane strikes such a droplet, there is provided the necessary agitation

and freezing begins. But not all of the droplet will freeze at once. It is known that to freeze 1 cc. of water 80 calories must be removed therefrom. It is also known that at the instant the droplet begins to freeze the temperature of the mixture of ice and water will immediately rise to 0° C. Actually, the temperature of the droplet will rise only to the freezing point of the particular solution dealt with, because that is the only temperature at which ice and the solution are in equilibrium. However, since the exact concentration of the solution is not known, and since dilute solutions are dealt with, for simplicity assume that the temperature rises to 0° C. This rise in temperature to 0° C. can only be accomplished as a result of heat being added, while at the same time heat is being taken away from a portion of the droplet in order to bring about the freezing. Assuming that no heat is provided from without, this added heat must be removed from that portion of the droplet which freezes. Thus the rise in temperature of the mixture from –8° C. to 0° C. will give a measure of the number of calories required to produce this heating and, thereby, indicate the fraction of the droplet which is immediately frozen on impact. In this example, since it requires 1 calorie to raise the temperature of 1 cc. through 1 degree C., it will require $1.4 \times 10^{-8} \times 8$, or 11.2×10^{-8} calories. And, since it requires the expenditure of 80 calories to freeze 1 cc., cooling has been provided sufficient to freeze $(11.2 \times 10^{-8}/80)$ cc. which represents 10% of the volume of the droplet. If it is assumed that the droplets have a higher initial temperature, say –4° C., it would be found that only 4/80, or 5% of the water would be frozen on impact. Thus it can be said that the amount of water encountered by the plane in the form of cloud particles or rain drops, and which is immediately frozen, is directly proportional to the degree of under-cooling of the droplets.

If it was only that portion of the droplet which freezes on impact that concerned us, the remaining portion was permitted to run off as water, the icing of aircraft would not be of much importance. It is because a very large part of the remaining water also freezes that the icing conditions are considered such a hazard. It is through the operation of the process of evaporation that the remaining portion of each droplet is largely turned to ice.

Consider, again, the original droplet, 10% of which has been changed into ice, while the remaining 90% exists as water at a temperature of 0° C. Over this water at 0° C. there is a saturation vapor pressure of 6.11 millibars, whereas the surrounding cloud air will have a saturation vapor pressure corresponding to the temperature of –8° C., or only 3.12 millibars. Thus evaporation will take place from the water surface just as observed in the section on condensation that the smaller cloud droplets with higher vapor pressure evaporated and condensed on the larger droplets of lower vapor pressure. To accomplish the evaporation of 1 cc. of water it requires the addition of approximately 600 calories. For this particular average droplet it will require $1.4 \times 10^{-8} \times 600$, or 8.4×10^{-6} calories. To freeze the remaining 90% of the original droplet 90% of this amount needs to be removed, or $1.4 \times 10^{-8} \times 80 \times .90$, which equals 1.008×10^{-6} calories. Hence it is only necessary to evaporate $(1.008 \times 10^{-6}/8.4 \times 10^{-6})$ or 12% of the original droplet. Thus it is clear that the process of evaporation is of first importance in any consideration of icing conditions. Under the conditions chosen for this example, roughly 88% of the water encountered by the plane would be frozen, nearly nine tenths of which is caused by evaporation. The size of the cloud particle has no influence on the part of each that is frozen either on impact or through subsequent evaporation. A particular size of droplet was used in the computation only for the purpose of making the illustration specific.

Just as it is found that the portion of each droplet frozen on impact is directly proportional to the degree of under-cooling, so is it true that the rate of evaporation of the remaining liquid portion, and the total amount to be frozen, will be directly proportional to the degree of under-cooling. If one starts with a temperature of –20° C., 25% of each droplet will be frozen on impact. Only one tenth of the droplet need be evaporated to freeze the remaining portion and, due to the relative great difference between the saturation vapor pressure over water at 0° C. (6.11 mb.) and that of the cloud air at –20° C., (1.04 mb.), this evaporation will take place about 3 times as rapidly as in the case where a cloud air temperature of only –8° C. is assumed.

It should be noted that in these examples a relative humidity of 100% in the cloud air has been assumed. As has been mentioned above, and as shown in Table 1 (omitted), clouds often occur with relative humidities considerably below 100%. The values noted in this study where clear ice formations were reported, ranged from 51% to 100%, with the average being about 90%. Under such conditions there would exist a still greater difference in vapor pressure between that for the water on the wing of the plane and that in the free air. Hence evaporation and the resultant freezing would take place more rapidly. This consideration would seem to suggest that icing would take place more readily while flying through portions of a cloud or fog wherein the relative humidity is lower. This also explains the observed rapid formation of ice as the plane emerges from a cloud into the comparatively clear air above or below.

In a few instances ice has been reported as occurring at temperatures above freezing. This does not occur often, but it is theoretically possible. Two cases of this kind were among the observations of this study.

EXTRACT FROM TABLE 1

	Average elevation at which formation began (meters)	Average elevation at which formation ended (meters)	Average thickness (meters)	Clouds		
				Average elevation of base (meters)	Average elevation of top (meters)	Average thickness (meters)
Clear ice	2890	3362	551	2824	3251	553
Rime	3205	3768	507	3128	3695	613

The explanation of this phenomenon depends on the assumption that the relative humidity within the cloud is less than 100%. A temperature of 2° C. is about the upper limit for ice formation. If an air temperature of 2° C. and a relative humidity of 100% is assumed, the vapor pressure of any water striking the plane will be exactly the same as that of the cloud air. Hence there will be no evaporation and no freezing. If, however, the same air temperature is assumed, but now a relative humidity of 90%, there would be a difference in vapor pressure of 0.705 millibars. A certain small amount of evaporation would take place and a very little freezing. The temperature of the ice and water on the plane would be lowered to 0° C. At this point the saturation vapor pressure of the ice and water mixture would be essentially the same as that of the cloud air. Hence no further evaporation would take place. Under such conditions, therefore, ice would form very slowly because of the small difference in vapor pressure and the deposits would be small.

The formation of ice at temperatures above 0° C. is also, in part, caused by evaporation brought about by the adiabatic cooling of air in passing over the vacuous space above the airfoil.

If a cloud air temperature of 0° C. is assumed there is no expenditure or gain of heat in bringing the water and ice mixture to a temperature of 0° C. But here any evaporation which may be started by encountering cloud air of less than 100% relative humidity will require the expenditure of the heat of evaporation. Since to freeze 1 cc. of water it is only necessary to remove 80 calories, only 80/600 or 13.3% need be evaporated. Cloud air with a temperature of 0° C. must, therefore, be considered dangerous along with that found at lower temperatures.

DISCUSSION OF OBSERVATIONAL DATA

A study of teletype reports of upper air soundings, made in the United States during the winter of 1934–35, and in which ice formations were reported, formed the basis of an effort to establish some correlation between the type of ice encountered and the degree of atmospheric stability and turbulence. Sixty-six such soundings were listed. A table was prepared for the original manuscript in which the following data were recorded for each sounding: type of ice, type of air, altitude of the base and the top of the ice formation, type of cloud in which the ice was observed, altitude of the base and top of the cloud, the temperature at which the ice was first and last observed, and the relative humidity at the beginning and end of the ice formation. This table has been omitted from this paper on account of its length, but has been referred to herein as Table 1.

In addition, a frequency chart was prepared, showing the percentage frequencies for clear ice and rime formations at the temperatures at which the formation began. This chart has also been omitted from the present paper.

One of the most convincing features of these data is the close conformity of the regions wherein ice was encountered to the region of cloudiness. This may be seen from the extract from Table 1.

It has often been claimed that both clear ice and rime are formed, at times, above and below clouds. This, of course, may happen as is suggested by the explanation offered for the formation of ice at temperatures above 0° C. That is to say that under such conditions water on the aircraft must first have been accumulated and then encounter a zone wherein the relative humidity is less than 100%. This latter condition can be realized by going above or below the cloud. But here, by going above the cloud, there would be no new supply of water to be encountered and only that small portion which had adhered to the craft would be frozen. Hence under these particular conditions the danger of icing would be very small but the formation would take place very rapidly. On the other hand in the region of falling rain below a cloud there would be a continuously new supply of water spreading over the craft. Doubtless this is a favorable zone for ice formation under particular situations wherein the temperature and humidity values are appropriate. In falling rain within the warm sector of a cyclone, the temperatures will usually be too high for ice to form. But then, little rain falls within the warm sector except in the summer months. In the region of falling rain below a warm front, the relative humidity of the surface cold air will be too high to permit of rapid evaporation. The rain which is falling from the upper warm stratum is probably not under-cooled and no freezing results from the mere agitation on impact. The principal danger in this zone seems to be due to the low

temperature acquired by the plane in flying through the lower cold air and which serves to freeze the water encountered by conduction. The infrequent reports of ice forming below clouds is undoubtedly due to the fact that the low ceilings and poor visibility attending such meteorological situations have operated to prevent the flights. Only one case is listed in Table 1 wherein ice was encountered below the base of the cloud. Only two cases were listed wherein ice was reported in regions above the cloud.

It is in the realm of low temperatures that water exhibits its most capricious behavior. The soundings studied show that clear ice was observed forming at temperatures ranging from 2° C. to –22° C., while rime was observed at temperatures from –2° C. to –28° C. Thus it would seem that temperature alone is not a safe criterion upon which to judge the type of ice formation to be expected. It should be expected that clear ice will form at higher temperatures than those in which rime is formed because, as explained above, the smaller amount the temperature is depressed below 0° C., the smaller will be the portion of each droplet frozen on impact. Hence a relatively large amount is left in liquid form to spread out in the familiar mushroom shape and freeze into clear ice by subsequent evaporation. In the case of a larger depression of the temperature of under-cooled droplets, it is found that a very large portion of the droplet will be frozen directly on impact. And in the case of very small droplets the speed of crystallization may be so rapid as a result of the large amount of initial freezing and the relatively small amount remaining to be frozen through evaporation, which process will be aided by the large difference in vapor pressures at the lower temperatures, that there would be little or no spreading of water, but instead the almost immediate and complete freezing of the entire small droplet. Thus with lower temperatures and smaller droplets rime should be expected to form. With higher temperatures and larger droplets clear ice should be expected. The average temperature of the base of clear ice formations was –6.6° C., while the average temperature of the base of rime formations was –11.1° C. The frequency chart referred to showed clearly the prevalence of clear ice at the higher temperatures. Seventy-eight per cent of the clear ice reported occurred at temperatures of –8° C. or higher, while only thirty-six per cent of the rime reported occurred in this temperature range.

No data are available showing the relative size of cloud droplets during the ice deposits but it appears reasonable to assume that the smaller droplets are associated with rime deposits, while clear ice may be expected when larger droplets are encountered. In agreement with this it is to be expected that rime will be encountered most often in the region where convective action, sufficient to support the larger droplets, is absent, and clear ice will be found most often where relatively strong vertical currents are encountered.

It is misleading to attempt to show any correlation between the existence of icing conditions and the various types of clouds. This results from the difficulty of definitely classifying the clouds under all conditions, as well as the fact that flights are seldom made through certain kinds of clouds. For example, any curve showing the percentage frequencies for both clear ice and rime formations in the various cloud forms will show pronounced high frequency for alto-stratus clouds and pronounced low frequency for cumulus clouds. The high frequency for alto-stratus will be largely due to the fact that this type is a formless cloud which may often be reported when the observer has not been in position to observe the true form. The spreading top of the cumulo-nimbus, or the base of a wide-spread layer of thick alto-cumulus clouds may often quite reasonably be mistaken for alto-stratus clouds. On the other hand, the very nature of cumulus clouds, being considerably separated one from another, makes it almost always possible for the pilot to avoid flying through such clouds. Hence very few reports are found showing icing conditions within cumulus clouds. Providing temperatures are appropriate, there is no reason to say that any one type of cloud will yield icing conditions more often than another. It can only be stated that the type of ice encountered will be governed by the degree of turbulence or vertical motion associated with the cloud forms. Thus clear ice should be expected to be associated with those clouds wherein considerable vertical motion is encountered, and rime should be found most often in clouds wherein there is the absence of any considerable vertical motion.

A large number of characteristic curves were plotted for soundings in which ice was reported. These curves were studied in connection with the synoptic weather maps which agreed in time nearest to that of the sounding. The following relations were discovered:

(1) Clear ice occurs in unstable air or in a cloud which has been developed by instability just below the ice level and which has, through momentum, carried through a short distance into stable air.

(2) Clear ice occurs where considerable turbulence prevails.

(3) Rime occurs in stable air and where little or no turbulence prevails.

A few illustrative examples of soundings, wherein clear ice and rime were encountered, will be discussed below:

Clear ice was encountered during a sounding which was made at Spokane, Wash., on November 2, 1934. The weather map of that date showed Spokane to be in Polar Pacific air a short distance behind a cold front type occlusion. Strong upper winds from the W and WNW, with resulting turbulence, prevailed. The lifting of this air, which had a four day trajectory

over a water area and was therefore very moist, as it passed over the occluded front and the mountain ranges, may be expected to develop considerable instability. The characteristic curve, as plotted on the Rossby chart, shows both convective instability and turbulence. Thus, in this sounding, all features indicated the existence of considerable vertical motion, sufficient to support large droplets. Hence, if appropriate temperatures were to be encountered, clear ice should be expected.

Clear ice was reported in a sounding made at Spokane on November 20, 1934. Here much the same conditions prevailed as referred to in the preceding example, except that a lesser degree of turbulence was shown, due to smaller values of upper wind speeds. The characteristic curve shows the ice to have formed in air that is practically in equilibrium, but which is immediately above an unstable stratum wherein considerable vertical motion undoubtedly prevailed.

Rime was reported at Billings, Montana on December 6, 1934. Both the synoptic chart and the characteristic curve show this sounding to have been made in stable air throughout. Further, the winds at upper levels are nearly parallel to the mountain range and therefore can not be expected to produce much turbulence. It should be noted also that the rime was reported in stratus clouds between 1700 meters and 1900 meters. Stratus clouds are distinctly lacking in vertical motion, which condition it has been observed is favorable for the formation of rime.

Clear ice was reported in a sounding made at Spokane on December 25, 1934. Here the ice formed in stable air which was immediately above a zone of convectively unstable air. The characteristic curve shows that considerable turbulence prevailed, as might be expected from the strong pressure gradient and general orientation of the isobars.

Clear ice was reported from Spokane on January 27, 1935. Rime was reported in a sounding made at Murfreesboro, Tennessee on the same day. The clear ice was observed in an over-running branch of Polar Pacific air at Spokane in a zone which was in equilibrium and above a turbulent stratum of 1380 meters thickness, and which latter was convectively unstable. Rime was observed in the Murfreesboro sounding in stable Polar Continental air, wherein no vertical motion prevailed. It is interesting to note that on this date, clear ice formed at Spokane at a temperature of –10° C., while rime formed in the stable air at Murfreesboro at a temperature of –8° C., thus showing that the degree of stability or instability is a far better criterion of the type of ice to be expected than is the temperature.

In summary, the following conclusions are made:

(1) Icing conditions may be expected in any form of cloud wherein the temperature is 2° C. or below.

(2) The danger of icing conditions in regions above cloud forms is not great.

(3) Ice may be formed in rain below a warm front surface of discontinuity provided the lower cold air has cooled the aircraft surfaces below 0° C.

(4) Clear ice will predominate at temperatures of –8° C. or above.

(5) Clear ice may be expected in clouds with appropriate temperatures, where vertical currents, strong enough to support the larger cloud droplets, are found. These currents may be expected when the following conditions prevail:

(a) Convective action resulting from the heating of surface layers.

(b) Convective over-turning or the forcing aloft of warm air at the forward portion of the cold front.

(c) Active upglide of warm moist air over a warm front.

(d) The lifting of cold moist air under the warm front due to the convergence of stream lines along the warm front.

(e) The lifting of unstable air over mountain ranges.

(f) All of these conditions will be shown on the Θ_E diagram as being within a layer of unstable air or, if in a stable layer, this latter will be immediately above an unstable zone.

(6) Rime will predominate at temperatures below –8° C.

(7) Rime may be expected in clouds, with appropriate temperatures, wherein vertical currents are not strong enough to support the larger droplets.

(8) The Θ_E diagram will indicate stable conditions within the zone of rime formation.

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Institute Notes

Fifth Annual Meeting

The Fifth Annual Meeting of the Institute, to be held on January 27–28–29, will be even more comprehensive in scope than those held in former years. Members will all receive the program of the sessions by mail and a complete account of the meeting will appear in the Journal for February. As special features in addition to the technical sessions, there will be a showing of the moving pictures of English, German and Italian aeronautical laboratories and wind tunnels, and a practical demonstration of the radio-meteorograph by simulated ascents to a fifty thousand foot altitude.

At the Annual Meeting of members, they will receive reports of the progress of the Institute and officers will be elected for 1937.

The Annual Dinner will, as usual, be informal, and in addition to interesting speeches will be the occasion for the presentation of the *Sylvanus Albert Reed Award* and the new *Lawrence B. Sperry Award.*

Visitors to the Institute

Foreign visitors who have been received at the Institute recently are: Dr. Ing. Thiedemann and Dr. Ing. E. von Brauchitsch, Directors of the Junkers Werke, Dessau, Germany; V. A. Miassistchev; Anatoli A. Senkov, Central Aero-Hydrodynamic Institute, Moscow; Otto Occkl, Henschel Werke, Berlin; E. J. C. Rennie, Melbourne, Australia; H. M. Antz, D.V.L., Berlin; Ragnar F. Bengtson, Stockholm, Sweden; Lt. F. Tagil, Stockholm; Gordon P. Olley, London, England; C. Kolff, Amsterdam, Netherlands.

The Aeronautical Index

The Aeronautical Index W.P.A. project which the Institute has sponsored for the past two years is consulted by many visitors and many enquiries are answered by mail. The Index contains over 400,000 cards and specialized bibliographies are being prepared which will be distributed when they are processed. Those which have been completed are *"Propellers," "Stratospheric Flight," "Rocket Propulsion," "Women in Aeronautics,"* and *"Airports."* These are now available for reference at the Institute.

Request

Members who have books which they wish to present to the Library of the Institute should send lists to the Secretary so that the gift of duplicate volumes will be avoided.

Student Branches

New York University. A meeting of this Student Branch was held on Friday, December 11, 1936, in the Guggenheim Building of the University. Dr. Alexander Klemin, head of the aeronautics school, spoke on the benefits received from membership in a society such as the Institute. Michael J. Phillips, instructor in airplane design, spoke on employment in the aeronautics industry at the present time.

Louisiana State University. At the initial meeting of this branch for the session of 1936–1937, F. A. Ford, Jr., President; J. L. Frederick, Vice-President; and R. L. Montoney, Secretary-Treasurer, officers elected last spring, presided. The meeting was held on October 26 in the Aeronautics Laboratory.

An interesting talk on "High-Speed Aircraft" was given by E. E. Maser, formerly with the Fokker Aircraft Company and at present a member of the faculty of the University in the College of Aeronautical Engineering.

Another meeting of this branch was held on November 17, at which time William Downs, senior in the College of Aeronautical Engineering, presented an interesting discussion on the development of Diesel aircraft engines and their present adaptability, referring to the Dornier and Junkers airplanes now equipped with the newly developed Jumo twin-piston diesel engines.

University of Michigan. A meeting of this Student Branch was held Thursday, December 3, in the West Engineering Building of the University. About forty members were present. B. L. Springer, Honorary Chairman, spoke on the Annual Meeting of the Institute to be held in January. Inspection trips for the branch were planned for the year, and included the Stinson Aircraft Corporation, the Wayne County Airport, and the Barkley-Grow Aircraft Corporation.

Lieutenant Charles Donald Griffin, Naval officer and graduate student in Aeronautical Engineering, spoke on the naval aviation flight course at Pensacola, and his experiences while in active service.

Personnel Opportunities

The Personnel Bureau serves organizations seeking to employ aeronautical specialists as well as individual members. The Bureau has been the means of arranging several very successful connections for members.

Any member or organization may have requirements listed without charge.

Wanted

Detailers and weight men desired by eastern aircraft company. Experienced men only and preferably those with military aircraft experience. Connection is permanent for right men. Write Box 53, Institute of the Aeronautical Sciences.

Available

A. and E. Licensed Mechanic and Transport Pilot. Also holding British B pilot's license, 2nd class air navigator's license and ground engineer's licenses. Fluent knowledge of Spanish, French, German, Dutch. Considerable flying and operating experience throughout U. S. and abroad. Extensive knowledge of Dept. of Commerce, Air Ministry and foreign government regulations and requirements. Would welcome any opportunity where above qualifications could be used to full advantage. Write Box 50, Institute of the Aeronautical Sciences.

Engineer Executive available for consultation or permanent position. Long experience in charge of engine design, development and construction for the U. S. and foreign governments and private companies. Write Box 51, Institute of the Aeronautical Sciences.

Recently graduated Student Members of the Institute wishing to secure some connection in the industry have forwarded to the Institute complete biographies and records of their school work. It would be appreciated if members or organizations offering employment to this type of personnel would write Box 52, Institute of the Aeronautical Sciences, stating their requirements.

Letter to the Editor

Dear Sir: December 29, 1936.

As is well known, any radio transmitter is most temperamental with respect to putting its power out into an antenna circuit. The load resistance of the antenna circuit must match the resistance of the output of the transmitter, otherwise a great inefficiency occurs between the two and little or no power is radiated. Any kind of an antenna has the unfortunate characteristic of changing its characteristic and load impedance with frequency, for a given length of wire may be a pure resistance on one frequency, represent a capacity at another frequency and an inductance at still another frequency. In the case of fixed antennae this involves the necessity of cancelling out these reactions by suitable loading means in the transmitter. Where a transmitter is designed to operate on a number of frequencies, this involves considerable complication in design and operation.

It has been found that an antenna of approximately one-quarter wave length has an input terminal impedance of approximately 35 to 40 ohms. It is quite easy to adjust the transmitter to have an output impedance of 40 ohms at any frequency. From this it is obvious that if a quarter wave antenna could be used on all of the frequencies desired, that there would be no matching problem and that maximum efficiency would be obtained from the transmitter. In order to have a quarter wave antenna for every frequency to be used, it is necessary to make the antenna variable in length. It is easy to adjust the antenna to its proper length by watching the increase in antenna current until it reaches its maximum while the antenna is being extended or retracted.

The objection to most systems involving a variable wire length of this kind has been the losses incurred due to leading the antenna wire from the transmitter to the hand reel which, of course, must be adjacent to or available to the pilot. Using a Motoreel this is eliminated because the reel is located adjacent to the transmitter, necessitating only a short lead and practically no losses and the antenna passes directly out of it through the belly of the ship. This materially increases the efficiency of the installation and insures maximum power radiation over a wide range of frequencies, at the same time making it possible for the pilot to select the proper length of wire by remote control, and also keeps the cockpit from becoming cluttered up with bulky as well as dangerous hand reels.

WM. P. LEAR
Lear Developments, Inc.

Book Reviews

Jane's All the World's Aircraft, 1936, compiled and edited by C. G. GREY and LEONARD BRIDGMAN; Sampson Low, Marston & Company, Ltd.; 42s.

For twenty-six years this annual has been the standard international reference guide to governmental aviation and aircraft. C. G. Grey and Leonard Bridgman collect and edit the vast amount of information presented with great patience and skill. The five sections of the book deal with The World's Aeronautical Progress of Civil Aviation of 55 countries; Service Aviation of 47 countries; the airplanes manufactured in thirty countries; the aircraft engines produced in seventeen countries and the airship progress of six countries.

The Preface by Mr. Grey gives some idea of the scope of the types of aircraft listed.

"Some idea of what there is to see in *All the World's Aircraft* this year may be gathered from figures from the Aeroplane Section. In all 616 aeroplanes are described and most of them are illustrated. Of these 249 are new machines which did not appear last year. Of the others a good many have been modified or else information is available which was not available a year ago.

"In the British section of 106 aeroplanes 35 are new. In the French section of 109 there are 40 new machines. In the German section of 35 there are 10 new. In the Italian section of 57 there are 18 new, and in the United States section of 150 there are 57 new.

"The high proportion of new machines is interesting in view of the careful way in which all countries which are now rearming withhold information about their new types till the last moment.

"An interesting point about Japan is that, although the country has a very large Air Force and is quite generous in allowing photographs and descriptions to be published of types which its Flying Services have in regular use, there is a surprisingly small number of different types. Only 16 different types of Japanese aeroplanes are shown, but of these eight are new.

"In Czechoslovakia, of 21 aeroplanes 15 are new, chiefly because an entirely new manufacturing concern has come into existence with half a dozen new types. In Holland of 29 machines 15 are new, another high proportion due to the ingenuity of the two famous designers in the Netherlands.

"The Airship Section is still a sadly shrunken area but the striking success of the Hindenburg in the Airship Section is of unusual interest."

Pictorially, this year's volume is especially informative, as views of many of the new flying fields and airports, which are only dots on the aerial maps of the world, show the world-wide progress of air transportation.

With the growing tendency toward secretiveness as to the newest designs of aircraft, the difficulty of securing photographs and descriptions has increased but each year the editors secure an amazing number of new machines which makes the preceding volume obsolete.

Once more those engaged in aeronautical engineering work are placed under an obligation to the compilers for providing this essential requirement of every aeronautical library no matter how small. In fact it can be said with confidence that Jane's *All the World's Aircraft* should be the starting volume of any aeronautical collection.

LESTER D. GARDNER

Flying for 1937, written and compiled by HOWARD MINGOS; Aeronautical Chamber of Commerce of America; 256 pages, $1.50 U. S. & Canada, $2.00 elsewhere.

Flying for 1937 is the fourth edition of the popular aircraft book which embraces in its 256 pages eleven chapters on activities in various branches of aviation today, with the material from official sources. The 175 photographic illustrations and 80 drawings are also from official sources.

The book is not technical in its treatment of aviation but is a condensed survey of the progress aircraft have made during the year. It will be found of interest by readers of all ages, the younger enthusiasts for the adventurous and popular side of flying and others for the factual presentation of the year's accomplishments in the aeronautical field.

Exchanges

The Institute exchanges the Journal with many other aeronautical periodicals. They are kept on file at the Skyport in Rockefeller Center, New York City, where members may read them. As readers of the Journal may wish to subscribe to some of them, a list of these periodicals with their addresses is published here. Information regarding subscription prices may be secured from the Secretary of the Institute.

Aero, Maneesikatu 2, Helsingfors, Finland.

Aero Digest, 515 Madison Ave., New York City.

Aeronautica Argentina, Velez Sarsfield 57, Cordoba, Argentina

L'Aeronautique, 55 Quai des Grands-Augustins, Paris, France.

L'Aerophile, 7 Rue Saint-Lazare, Paris, France.

The Aeroplane, 175 Piccadilly, London, W.1, England.

L'Aerotecnica, Via delle Coppelle 35, Rome, Italy.

Les Ailes, 77 Boulevard Malesherbes, Paris, France.

Aircraft Engineering, 2 Bloomsbury Place, London, E.C.1, England.

Air Law Review, Washington Square East, New York City.

Asas, Caixa Postal 1967, Rio de Janeiro, Brazil.

Astronautics, American Rocket Society, 31 West 86th Street, New York, N. Y.

Aviation, 330 West 42nd St., New York City.

L'Aviazione, Corso Umberto 504, Rome, Italy.

Boletin de Aeronautica Civil, Calle Azcuenaga 923, Buenos Aires, Argentina.

Boletin Oficial de la Direccion General de Aeronautica, Magdalena 12, Madrid, Spain.

Bulletin du Service Technique de l'Aeronautique, 72 chaussee de Waterloo, Rhode-Saint-Genese, Belgium.

Bulletin of the American Meteorological Society, Blue Hill Observatory, Milton, Massachusetts.

Bulletin Officiel du R.A.A., 6, Rue de Mezieres, Paris (6), France.

Bulletin Technique du Bureau Veritas, 31 rue Henri-Rochfort, Paris (17), France.

Canadian Aviation, Journal Building, Ottawa, Canada.

Deutsche Luftwacht, Schoeneberger Ufer 46, Berlin W35, Germany.

Les Fiches Aeronautiques, 6 rue Galilee, Paris, France.

Flight, Dorset House, Stamford St., London, S.E.1, England.

Flugwesen, Konviktska 22, Prague 1, Czechoslovakia.

The Gliding and Soaring Bulletin, Soaring Society of America, Pensacola, Florida.

Indian Aviation, P. O. Box 2361, Calcutta, India.

Interavia, 13, Corraterie, Geneva, Switzerland.

Journal of Air Law, Northwestern University, Chicago.

Journal of the Institute of Engineers, Australia, Science House, Gloucester and Essex Sts., Sydney, N. S. W., Australia.

Journal of Research of the National Bureau of Standards, U. S. Govt. Printing Office, Washington, D. C.

Journal of the Royal Aeronautical Society, 7 Albemarle St., Piccadilly, London, W.1, England.

Journal of Scientific Instruments, 1 Lowther Gardens, Exhibition Rd., London, S.W.7, England.

Journal of the Society of Automotive Engineers, 29 West 39th St., New York City.

Letectvi, Celetna 13, Praha I, Czechoslovakia.

Luftfahrt-Forschung, Verlag Oldenbourg, Munich 1, Germany.

Die Luftreise, Lindenstr. 35, Berlin SW68, Germany.

Luftfahrt-Literaturschau, Z.W.B. bei der D.V.L., Berlin-Adlershof, Germany.

Model Airplane News, 551 Fifth Avenue, New York City.

Model Aviation, The American Academy for Model Aeronautics, 1733 RCA Building, Rockefeller Center, New York, N. Y.

Monthly Weather Review, U. S. Dept. of Agriculture, Washington, D. C.

Motor and Flying, 24 Bond St., Sydney, N. S. W., Australia.

National Aeronautic Magazine, Dupont Circle, Washington, D. C.

Official Aviation Guide, 608 S. Dearborn St., Chicago.

The Pilot, Grand Central Air Terminal, Glendale, California.

Il Politecnico, Via Spiga 32, Milan (2/7), Italy.

Popular Aviation, 608 S. Dearborn St., Chicago.

Proceedings of Institute of Radio Engineers, 330 W. 42d St., New York City.

Publications Scientifiques et Techniques du Ministère de l'Air, 55, Quai des Grands-Augustins, Paris, France.

Review of Scientific Instruments, 175 Fifth Ave., New York City.

Revista de Aeronautica, Ministerio de la Guerra, Apartado 1047, Madrid, Spain.

Revue de l'Armee de l'Air, 55 quai des Grands-Augustins, Paris, France.

Revue du Ministere de l'Air, 71 avenue des Champs-Elysees, Paris, (8), France.

Rivista Aeronautica, Ministero dell'Aeronautica, Rome, Italy.

The Royal Air Force Quarterly, Gale & Polden Ltd., 2 Amen Corner, London, E.C.4, England.

Southern Flight, Ledger Building, Fort Worth, Texas. Texas.

Sportsman Pilot, 515 Madison Ave., New York City.

Technical News Bulletin of the National Bureau of Standards, U. S. Govt. Printing Office, Washington, D. C.

Technika Vosdushnogo Flota, U1. Radio 16, Moscow 16, U. S. S. R.

La Technique Aeronautique, 2 rue Blanche, Paris (9), France.

U. S. Air Services, Transportation Building, Washington, D. C.

Western Flying, 420 S. San Pedro St., Los Angeles, California.

Wirtschaft Technik Verkehr, Alte Jakobstr. 148/155, Berlin SW68, Germany.

Zeitschrift für angewandte Mathematik und Mechanik, Kulmstr. 1, Dresden A24, Germany.

AERONAUTICAL REVIEWS

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps.

Aerodynamics

Aerodynamics Symbols. Continental system of symbols adopted by the British Aeronautical Research Committee for its Reports and Memoranda. Aircraft Engineering, November 1936, page 310. 3 tables.

Generalized Kármán-Trefftz Profiles. A. Betz and F. Keune. For the construction of Kármán-Trefftz profiles a simple method is illustrated for those profiles which have a circular-shaped outline so that a S-turn is superimposed. Since this case is a process of a conformal representation, the total flow of these profiles, particularly the pressure distribution, can be easily determined. Report of the Aerodynamischen Versuchsanstalt at Goettingen. Luftfahrtforschung, October 12, 1936, pages 336-345. 21 illustrations. 2 tables. 98 equations.

The Jet Effect in Open Wind Tunnels. F. Weinig. Influence of the fixed tunnel walls in front of and behind the working section of an open-jet wind tunnel was investigated for a jet of circular section and for wing models of relatively small span compared to the tunnel diameter. Conditions in this type of tunnel are shown to differ to an appreciable extent from those in a free jet unbounded longitudinally. A considerable reduction is necessary in the corrections required for the angle of incidence and drag of wings and for the setting angle of the elevators when the results of model tests are applied to full-scale aircraft design. Report of the DBL. Luftfahrtforschung, July 20, 1936, pages 210-213. 6 illus.

Theory of Airfoils in a Compressible Medium. L. Prandtl. A new formula is given for the theory of lifting surface, and various flow potentials produced by stationary sources and by movable sources variable as to time are calculated. These relations are then applied to the infinitely long wing at supersonic speed. Luftfahrtforschung, October 12, 1936, pages 313-319. 5 illus. 30 equations.

Wing Theory at Supersonic Speed. H. Schlichting. A theory for the wing of finite span at supersonic speed is developed in an analogy to the Prandtl wing theory of incompressible flow of 1918/19. The lifting curve with constant lift distribution (horseshoe vortex), the wave and reduced resistance, as well as warping, for a trapezoidal wing with constant lift density, and the lift distribution and drag for an unwarped rectangular wing are calculated. Luftfahrtforschung, October 12, 1936, pages 320-335. 20 illus. 2 tables. 102 equations.

Aircraft Design

For "Blowing" on a Wing. A. Payan. A jet of compressed air on the upper surface of a wing is said to prevent burbling and to permit high lift to be obtained. An unusual arrangement is described for the production of vapor heated to a high pressure which may be utilized for blowing on the upper surface of the wing during very brief periods in take-off and landing. Les Ailes, October 8, 1936, page 5. 3 illus.

Designing to Please the Air Traveller. A. E. Raymond. Trend in the design of air transports in regard to passenger comfort. Chair design, vision from the cabin, noise and vibration reduction, ventilation and heating, and an oxygen supply and pressure control at high altitudes are briefly reviewed. S. A. E. Preprint for Meeting, October 15 to 17, 1936, 6 pages.

Problems in the Design and Construction of Large Aircraft. R. J. Minshall, J. K. Ball and F. P. Laudan. Aerodynamic, structuaral and manufacturing problems in the design of the larger aircraft with reference to Boeing practice. Selection of airfoils, flutter, and flight control are briefly reviewed. Structural design considerations are examined in detail and include—distribution of dead weight in the wing, wing structure under flap-down loadings, advantages of tubular spar construction, relative thickness of the corrugations and covering, gusset design, best strength-weight ratios from tubular spar members, reinforcing, secondary bending effects in spar chords, weight distribution in wings, monocoque fuselage design, loadings found to be critical for the cantilever tail surfaces of large high-speed airplanes employing constant center-of-pressure wing sections, and problems of adequate rigidities for tail surfaces. Manufacturing problems cover templates, drop, hammer, steel heat-treatment facilities, machined fittings, fabrication of spars, and jigs, gages, and fixtures of extreme accuracy. S. A. E. Preprint for Meeting, October 15 to 17, 1936, 22 pages. 2 illustrations.

Problem of the Tailless Airplane and Its Solution in the Flauvel Flying Wing. C. Flauvel. Development of the Flauvel flying wing and its static and dynamic longitudinal stability, and transverse and directional stability as determined by wind-tunnel tests are described. Controllability and maneuvrability, and the aerodynamic qualities of the formula are also discussed. Object of the research described was the design of a tailless airplane having a static stability equal to that of the best type of airplane with a tail, complete manuevrability, a total drag at average and small angles, less than that of the best type of airplane with a tail, an advantage in weight, and simplicity of construction. Long discussion. L'Aéronautique, September 1936, pages 178-184. 4 illustrations.

The Vee Tail in Spin. A. V. Stephens. Experimental results obtained in 1932 on the Rudlicki oblique empennage in the free-spinning tunnel of the Royal Aircraft Establishment. The author believes it unlikely that under any conditions it would prove superior, in regard to spinning, to an ordinary tail unit with the bulk of the fin and rudder situated below the tailplane. Aircraft Engineering, November 1936, page 302.

What Air Transport Operators Want. Question of twin versus four motors, and suggested specifications for a transport for day services and for night services. Aeroplane, November 11, 1936, page 585.

Helicopters

Modern Helicopter Theory. V. Isacco. Types of helicopters built up to the present time are discussed from the point of view of their stability characteristics, including the Pescara, Bothezat, Oemichen, Florine, Ascanio, Asboth and Berliner and Brennan helicopters, the Breguet-Dorand gyroplane, the new Asboth helicopter, and the Isacco helicogiros. Concluded. Aircraft Engineering, November 1936, pages 303-308. 17 illus.

Stress Analysis and Structures

Application of Stress in Thin-Walled Cylindrical Shells. H. Wagner and H. Simon. Secondary stresses occurring with the introduction of longitudinal forces in cylindrical monocoque structures, such as open and closed profiles of smooth sheets, and stiffened shells for airplane fuselages. Exact calculation of the secondary stresses is explained and proof is given that the magnitude of the secondary stresses and their "damping out" can be estimated by a simple method. An integral equation is set up which describes the stress distribution at the point of application of the force in straight-walled and curved-walled shells. Report of the Flight Technique Institute of the Technische Hochschule at Berlin. Luftfahrtforschung, September 20, 1936, pages 293-308. 11 illus. 4 tables. English abstract. Aircraft Engineering, November 1936, pages 319-320.

The Buckling of an Elastically Encastred Strut. W. Prager. Buckling condition is given in a form containing immediately the total length of the strut. Brief comment on an article by N. J. Hoff previously printed in this magazine and reference to the author's article in a recent issue of the Journal of the Aeronautical Sciences. Royal Aeronautical Society Journal, November 1936, pages 833-834. 2 illus. 2 equations.

Designing for the Use of Aluminum Alloy Forgings and Extrusions in Aircraft Production. H. D. Houghton. Advantages to be gained in the use of aluminum-alloy forgings as compared to castings in aircraft, and technique of the aluminum-alloy forging process. Brief. S. A. E. Preprint for Meeting, October 15 to 17, 1936, 3 pages. 2 illus.

A Method of Figuring Shear and Torsion in Multispar Wings. F. Nagel. Method of finding the distribution of shear between spars. Journal Aeronautical Sciences, November 1936, pages 8-9. 2 illus. 3 equations.

Stress Distribution in Monocoque Airplane Structural Parts. H. Wagner. Stress distribution in monocoque fuselages and wing structures is dealt with as an equilibrium problem. Cylindrical and non-cylindrical shells, and the stress distribution at the point of introduction of the force at cut-out points are considered. Report of the Flight Technique Institute of the Technische Hochschule at Berlin. Luftfahrtforschung, September 20, 1936, pages 281-292. 29 illus.

Tests for the Determination of the Stress Bearing Width of Buckled Sheets. R. Lahde and H. Wagner. A more accurate method of determining the participating stress bearing width for the case of pure compression and the case of a sheet rigidly fixed along one edge to a section girder. From test results on the stress bearing width, the calculation is derived for the buckling load of a section connected to a thin sheet. Report of the Flight Technique Institute of the Technische Hochschule at Berlin. Luftfahrtforschung, July 20, 1936, pages 214-223. 22 illus.

Tests for the Determination of Stress Conditions in Tension Fields. R. Lahde and H. Wagner. Tension bay is designated as the thin-walled web plate of a sheet-metal girder which under the effect of a transverse force will buckle with the formation of diagonal folds. The theory permits the calculation of the magnitude and direction of the principal transverse stress in the web plate and of the stress in the vertical stiffeners and flanges, neglecting the bending strength of the web plates. In the tests described the stress in the elastic range in actual tension fields was investigated and the magnitude of the bending stresses caused by the formation of the folds was found. It is shown how, with small increases of stress beyond the buckling load, the bending strength of the web plate, neglected in the tension field theory, is the cause of a considerable relief of the load on the vertical stiffeners. Report of the Flight Technique Insstitute of the Technische Hochschule at Berlin. Luftfahrtforschung, August 20, 1936, pages 262-268. 21 illus. English abstract. Aircraft Engineering, November 1936, page 319.

Tests on the Strength of Thin-Walled Unstiffened Cylinders, under Shearing and Longitudinal Forces. W. Ballerstedt and H. Wagner. Endurance of thin unstiffened sheet-brass cylinders rigidly encastered at both ends when subjected to axial compression forces and shearing stresses about the axis, and the extent to which longitudinal forces influence the pure shearing strength are discussed. Report of the Flight Technique Institute of the Technische Hochschule at Berlin. Luftfahrtforschung, September 20, 1936, pages 309-312. 8 illus. 1 table.

Approximate Methods for Finding Frequencies of Vibration. Captain J. Morris. Raleigh's principle discussed is based on the proposition that in the fundamental mode of vibration of an elastic system, the distribution of kinetic and potential energies is such as to make the frequency a minimum. The case of a light elastic rod supported horizontally in any supports, the general case for any number of finite masses, approximations to the fundamental and higher frequencies obtained by using the principles somewhat on the lines of Ritz, the

case of a body encastré at one end, the case of "free-free" vibration, and the Dunkerley empirical formula are considered. The appendix contains a note on forced vibration experiments. Royal Aeronautical Society Journal, November 1936, pages 815-832. 5 illus. Many equations.

Aircraft

FRANCE

Dewoitine D338 Transport. The D338 twenty-six passenger monoplane is powered by three Hispano 9Vd 575-hp. engines and has a maximum speed of 300 km. per hour. Construction, characteristics and performance. L'Aérophile, September 1936, page 206. 2 illus.

The Mignet Pou-Du-Ciel. The Pou is unstable in normal flight with the C. G. further back than 40 per cent of the chord, and in a dive the instability becomes more marked. Results of tests carried out in the 24-ft. wind tunnel of the Royal Aircraft Establishment. R. A. E. Report No. B. A. 1333. Aircraft Engineering, November 1936, pages 309-310. 2 illus. 2 tables.

Mureaux-190. Light pursuit airplane powered with a Salmson 450-hp. engine. Photographs only. Les Ailes, October 22, 1936, page 1. 4 illus.

The Potez 56-E Naval Airplane. A. Frachet. Monoplane designed for operation from aircraft carriers is powered with two Potez 9-Ab 185 to 230-hp. engines, and has a maximum speed of 290 km. per hour and range of 1600 km. Long description. Les Ailes, October 8, 1936, page 3. 3 illus.

GREAT BRITAIN

The British Aircraft Industry Today. Performance figures and specifications for British military and civil aircraft of 1936 are given in a table followed by an account of the British aircraft produced during the past year and a few details of prototypes not yet built in quantities. Aeroplane, November 11, 1936, pages 588-611. 67 illus. 1 table.

British Civil Aircraft. Aircraft for private and commercial use. A few details regarding the products of 28 British aircraft firms. Flight, November 12, 1936, pages 488-496. 32 illus.

British Military Aircraft. Military aircraft of the Airspeed, Armstrong-Whitworth, Blackburn, Boulton Paul, Bristol, DeHavilland, Fairey, Gloster, Handley Page, Hawker, Parnall, Phillips and Powis, A. V. Roe, Saunders Roe, Short, Supermarine, Vickers, and Westland Companies. A few details illustrated with photographs and drawings. Flight, November 12, 1936, pages, 508a-508d, 509-514. 33 illus.

An Expansion Bomber. The Handley-Page Harrow heavy bomber has a long range coupled with large military load, full equipment of defensive armament, and slots and flaps. References to the design, three gun positions, and engine mounts. Flight, November 12, 1936, page 497. 2 illus.

Fifteenth of the Series. British exhibits at the Paris Aero Show are briefly discussed. Flight, November 12, 1936, page 484. 3 illus.

Ford-Powered. Wicko cabin two-seater powered with a Ford V-8 engine. The Ford engine has hardly been modified at all except for the arrangement of a double-helical spur reduction gear for the propeller, and the mounting is rigid. The airplane has a maximum speed of 115 m.p.h. Brief description. Flight, November 5, 1936, page 464. 2 illust.

The Four Winds. De Havillands are producing for the Air Ministry a training monoplane with one of the new D. H. Gipsy Twelve air-cooled inverted vee geared and supercharged engine developing over 500-hp.

Parnalls have designed a military general-purpose development of the Heck which is estimated to do 199 m.p.h. when powered with a Wolseley Scorpio II engine. Brief references. Flight, November 5, 1936, page 461.

The Westland Army Cooperation monoplane has taken off with full load in 120 yards and landed in 100 yards. Brief reference. Flight, November 12, 1936, page 486.

The Miles Mohawk. Colonel Lindbergh's long-distance airplane ordered from Phillips and Powis, Ltd. to his own specifications and to Mr. Miles' design. The airplane is powered by a Menasco Buccaneer 250-hp. engine and has four tanks in the wings to give a range of nearly 2000 miles. Brief description. Aeroplane, November 4, 1936, pages 576-577. 4 illus. Longer description with reference to a maximum speed of 200 m.p.h. Flight, November 5, 1936, pages 473-475. 8 illus.

Swift Poison. Vickers Venom single-seater fighter powered with a Bristol Aquila sleeve valve engine. Photograph only. Flight, November 5, 1936, page 471. 1 illus.

HOLLAND

War's Latest Weapon. In the Koolhoven F. K. 55 single-seater fighter the engine is mounted inside the fuselage between the main spars of the wings, so that it is placed just about the center of gravity and drives two oppositely-revolving propellers through a shaft and gear box. The airplane carries one cannon arranged to fire through the propeller shaft and two machine guns in each wing to fire outside the propeller disk. Powered with the Lorraine Petrel H. A. R. S. 860-hp. engine, the airplane has a maximum speed of 323 m.p.h. at 13,120 ft. Advantages of the design and specifications. Aeroplane, November 4, 1936, page 558. 4 illus.

ITALY

Savoia-Marchetti S-79 bimotored bomber of the Italian Air Force has a maximum speed higher than 430 km. per hour at 4000 m. with a useful load of 3600 kg. Photographs only. Les Ailes, October 22, 1936, page 8. 2 illus.

Jona J-6 Airplane with an Oscillating Wing. A. Frachet. Two-place touring sesquiplane is equipped with a Fiat 140-hp. engine and has an oscillating wing, with interceptors, and Handley-Page slots. Long description. Les Ailes, October 15, 1936, page 3. 4 illus.

U. S. A.

The Vought V-143 Single Seater Pursuit. Armament, characteristics, and performance. Brief. L'Aérophile, October 1936, page 220. 1 illus.

U. S. S. R.

A. N. T.-25. Large Russian long-distance metal monoplane, inspired by the Dewoitine D-33, is equipped with a M.34-R 950-hp. engine and has a maximum speed of 240 km. per hour and a range of 12,400 km. Long description. Les Ailes, October 22, 1936, page 3. 4 illus.

Propellers

First Tests of the Budig Propulsion System. J. Lacaine. The system is composed of two blades with a symmetrical biconvex profile, of about 36 per cent relative thickness and of constant chord parallel in each section to the longitudinal axis of the boat. The span is in the form of an arc of a circle. Tests of a boat with this means of propulsion, and an arrangement for tests in the air are discussed. L'Aéronautique, September 1936, pages 188-191. 7 illus.

Aircraft Operation and Maintenance

Operating Problems of Flying Boats. C. H. Schildhauer. Problems encountered in the Pacific Division of the Pan American Airways System with comments on a typical flight along the airway from Alameda to Manila. S. A. E. Preprint for Meeting, October 15 to 17, 1936, 7 pages.

Maintenance and Overhaul of Naval Aircraft. Commander F. W. Pennoyer, Jr. Corrosion, difficulty in assembly, normal wear, non-standard materials, defective welding, and forgings, castings, and extruded shapes hard to replace are discussed as presenting problems in overhaul and maintenance which the aircraft manufacturer should consider. Important checks and intervals for operating maintenance of naval aircraft and overhaul costs and time for engines and airplanes are given with an organization chart and layout diagram of an aircraft overhaul plant. S. A. E. Preprint for Meeting, October 15 to 17, 1936, 10 pages. 2 illus.

Aircraft Testing

Problems in Testing of Airplanes for Airline Service. M. G. Beard. Experimental and maintenance testing of modern transport airplanes with new equipment and appliances. Procedure in testing the operation and pitch settings of the Hamilton Standard constant-speed propellers, testing exhaust tail stacks, vibration study, correct procedure in experimental and maintenance testing of carburetor heaters, and airspeed indicator calibrations are discussed. S. A. E. Preprint for Meeting, October 15 to 17, 1936, 9 pages. 1 illus.

Planing Surface Tests at High Froude Numbers and Airfoil Comparison. A. Sambraus. For short flat hydroplaning bottoms, it was found that, as theoretically expected, the influence of gravity tends to increase drag. For long flat hydroplaning bottoms at high Froude number, previous expectations were unfounded, the airfoil analogy remaining valid, even at high angles of incidence. With the help of a single lift ratio curve it is possible to give lift ratios for hydroplaning surfaces of any length, even at finite angle of incidence. Even at finite angle of incidence the reduced mass is half the value occurring in the case of the wing. Contrary to earlier expectations the lift ratios do not vary linearly with angle of incidence. Luftfahrtforschung, August 1936, pages 269-280. 30 illus. 3 tables. English abstract. Aircraft Engineering, November, 1936, page 319.

Scale Effect in Towing Tests with Airplane Float Systems. R. Schmidt. DVL method and instruments used for determining the distribution of forces and moments on full-scale hulls and floats. Measured scale effect was found to conform satisfactorily with theory and plate- or planing-surface tests. Application of the roughening was not possible in the case of flotation tests, nor could the conversion method used in ship construction be applied. Model test results were on the safe side in calculation of take-off performance but for reliable preliminary calculation models of 1:25 of the full-scale size were required. Report of the DVL. Luftfahrtforschung, July 20, 1936, pages 224-237. 23 illus. Brief English abstract. Aircraft Engineering, October 1936, page 292.

The New Equipment of the DVL. M. L. Kirste. "The High-Speed Airplane: Development and Object," H. F. Hibbard. "Outline of Problems Concerning the Drag of Hulls," H. Wagner. "Construction of Nacelles and Results of Experiments," H. Hertel. "Some Problems Concerning the Study of Engines," R. S. Capon. "Medical Research in Aeronautics," H. Rein. "The Technical and Scientific Supervision of Air Transports," E. T. Allen. "The Possibilities of Radio and Its Importance for Aviation," W. Runge. Brief abstracts of papers presented before a Congress at the DVL and VLF followed by a brief but well-illustrated description of new equipment of the DVL. L'Aéronautique, L'Aérotechnique Sup., September 1936, pages 125-128. 10 illus.

Research Reports and Memoranda. Reports of the British Aeronautical Research Committee, German DVL, and Tokio University Aeronautical Research Institute. Brief abstracts. Aircraft Engineering, November 1936, pages 319-321.

Engine Design and Research

Aircraft Engine Installation Vibration Problems. J. M. Tyler. Two sets of exciting forces in the engine, propeller balance, aerodynamic excitation and flutter in aircraft, vibration response of a system, modes of vibration, and harmonics of excitation are explained and factors to be considered in developing an engine mount are taken up. Installation vibration is compared with engine vibration and propeller vibration and instruments used in making vibration studies of aircraft-engine resonance are described. Means of suppressing vibration in an engine mount and future developments are discussed. S. A. E. Preprint for Meeting, October 15 to 17, 1936, 24 pages. 12 illus.

Atmospheric and Pressure Charging of a C. I. Engine. W. A. Tookey. Series of tests carried out on a Crossley-Premier M. O. 6 6-cylinder horizontally-disposed compression-ignition oil engine with and without pressure charging. Description of engine, test method, and results. Engineer. November 6, 1936, pages 501-502. 5 illus. 1 table.

The Combustion Process in Internal Combustion Engines. A. V. Philippovich. Present knowledge of the combustion process in Otto- and Diesel-cycle engines is reviewed with special reference to knocking, and to pressure and temperature variations under different operating conditions. Research possibilities are discussed. Influence of the chemical, physical and engine conditions on normal and detonating combustion are considered. Engine influence on the mean combustion temperature, pressures at the end of compression and end of bombustion, and the rate of combustion are taken up for both the Otto-cycle and Diesel engine, and the engine influence on the heat transmission and catalyptic effects for the Diesel are pointed out. The value of cylinder-temperature measurements to explain otherwise inexplicable engine behavior is illustrated by results of tests carried out at the DVL on a C. F. R. engine which invariably yielded octane values which were too low. Paper presented before the German Bunson Society. Luftfahrtforschung, July 20, 1936, pages 199-209. 20 illus. 4 tables.

Conditioning the Air for Engines. E. Desparmet. Possibility of varying the quantity of oxygen contained in the air supplied to an internal combustion engine permitting the horsepower to increase proportionally. Les Ailes, October 8, 1936, page 5.

Horsepower Corrections for Supercharged Engines. M. Précoul. Variation of the atmospheric constants with altitude, decrease of horsepower with altitude, and French, English and Russian methods for the correction of horsepower for supercharged engines. Formulas and graphs are given for use in the calculation of horsepower curves at higher altitudes. L'Aéronautique, L'Aérotechnique Sup., September 1936, pages 113-118. 10 illus.

Mixture Strength in Petrol Engines Continuously Controlled by Electric Exhaust Gas Analysers. G. D. Boerlage and L. A. Peletier. The Cambridge (N. Y.) Aero Mixture aircraft-type indicator and the Lautz Phelps Motor Fuel Combustion Tester for Automobiles. Test results proving that electrical indications for showing mixture strengths may be of practical value to aircraft pilots. The indicators measure the thermal conductivity of the exhaust gas. Principles, influence of H/C ratio on instrument reading, construction of the instruments, calibration of the combustion indicators outside the engine, results of engine tests to determine the sensitivity to changes in gas pressure in the cell and the rapidity of indication of the instrument, effect of short-circuiting a spark plug, effect of detonation, influence of fuel composition measured in 4-cylinder Ford Model A and Ford V8 Model 48 engines, and calculation of the fuel/air ratio from the chemical composition of the exhaust gas determined by an Orsat apparatus are discussed. Royal Aeronautical Soc. Jour., November 1936, pages 799-814. 13 illus.

Special Steels for the Diesel Engine. S. F. Dorey. Resistance of the various steels to fluctuating stresses at normal and high temperatures, to wear, and to corrosion or chemical attack, and the steels suitable for crankshafts, connecting rods, and important bolts and studs. The discussion covers high-speed as well as low-speed Diesel engines. To be continued. Abstract of paper presented before the Diesel Engine Users Association. Heat Treating and Forging, November, 1936, pages 567-572.

Wind Tunnel Tests on the Drag of Air-Cooled Radial Aircraft Engines. J. Krueckel. Tests with cowled valve control gear showed that the shape of these cowlings must be very accurate in order to help in a decrease in drag. Exhaust pipes in an unfavorable arrangement may increase the drag of the cylinder by as much as 80 per cent, but with pipes leading to an annular manifold, an arrangement can be evolved which will produce only a slight increase in drag. In the case of a number of cylinders streamline fairing of the tappet rods of one cylinder reduced the drag by roughly 25 per cent of the original value and a decrease down to one-third the original value was obtained by cowling in the complete cylinder. In tests of the mutual interference of a number of cylinders, it was found that the installation of a few large cylinders was more favorable than that of a large number of smaller cylinders and the individual cowling of the cylinders was all the more advantageous with the smaller number of cylinders. Results given enable engine designers with the help of comparative designs to estimate the drag differences arising out of the different possible ways of grouping the cylinders into a radial unit. Tests of airplane-fuselage models showed that it was possible to reduce the drag due to the engine by one half by the addition of ring cowlings. Report of the Aerodynamic Institute of the Technische Hochschule of Aachen. Luftfahrtforschung, August 20, 1936, pages 239-261. 60 illus. 19 tables. English abstract. Aircraft Engineering, November 1936, page 319.

Engine Testing

The DVL Multicylinder Light Indicator for High-Speed Engines. By means of a practically inertia-free gas-discharge lamp, the DVL glow-lamp indicator records optically the mean time-pressure diagram. Diagrams for as many as 8 cylinders may be simultaneously obtained for a high-speed engine. The indicator has been developed for recording high-pressure and low-pressure diagrams and for remote control of the recording device. In addition, vibrations in the fuel, air and exhaust-gas lines can be recorded with this apparatus. Report of the DVL. Luftfahrtforschung, October 12, 1936, pages 357-360. 11 illus.

Electric Engine Testing Plant. Electric dynamometer used in aircraft-engine test laboratories with a reference to the DVL type. Aircraft Engineering, November 1936, pages 312-313. 8 illus.

Photoelectric Combustion Analysis. R. A. Rose, G. C. Wilson and R. R. Benedict. To indicate the behavior of the fuel in the combustion chamber the photoelectric set-up described was selected because of its high speed, its intensity, its zero time lag, and its freedom from inertia effects. A magnetic-type oscillograph for recording impulses, a cantilever-spring indicator for picking up the pressure impulse, and an amplifier between the photo-cell and oscillograph were used. Results of tests with a three-beam vibrator-type oscillograph are given with oscillograms for different fuels, loads and injection angles. Other tests using a cathode ray oscillograph and high-speed camera are described. Twenty-four varied Diesel fuels were studied. S. A. E. Journal, (Transactions), November 1936, pages 459-468. 14 illus. 2 tables.

Engines

British Aero Engines. A few details of the products of 20 British engine firms with a table of specifications. Flight, November 12, 1936, pages 501-508. 23 illus. 1 table.

British Aero Motors of 1936. Table of specifications of British aircraft engines and an account of the products of British aircraft-engine firms. Aeroplane, November 11, 1936, pages 592, 612-616. 25 illus. 1 table.

Heavy Oil Engines. L. Keleyan. Coatalen Sunbeam 12-cylinder engine transformed from a gasoline to a fuel-injection engine, the Continental two-cycle 6 cylinder radial, the Daimler LOF-6 12-cylinder 800-hp. engines powering the LZ-129 airship, the Mercedes Benz OF2, the Deschamps 12-cylinder liquid-cooled 1200-hp., the Guiberson 9-cylinder 240-hp. radial, the Humboldt-Deutz 2-cycle air-cooled radial, the Jalbert, the Junkers, and the Mann engines are discussed with a table giving principal characteristics of heavy-oil aircraft engines. Continuation. L'Aérophile, September 1936, pages 207-210. 11 illus. 1 table.

Large Air-Cooled Engines. Hispano-Suiza 79-02 14-cylinder 980-hp. radial, Renault 14-cylinder 1000-hp. radial, Napier Halford Dagger 22-cylinder 700-hp. H, and the Gnôme-Rhône K-14-cylinder radial engines. Characteristics and performance. L'Aérophile, September 1936, pages 205-206. 4 illus.

The New Bristol Aero-Motors. Cylinder heads of the new engines have been entirely redesigned and the area of the cooling fins increased by 40 per cent over that of previous type. The total finned cooling area of the whole motor is now 166.5 sq. ft. Very long well-illustrated description of the newest range of poppet-valve engines comprising the highly supercharged Mercury VIII and IX 840-hp., the medium-supercharged Pegasus X and XI, 915-hp., the highly supercharged Pegasus XIX and XX 925-hp., and the civil-rated Pegasus Xc 830-hp. engines. Aeroplane, November 4, 1936, pages 562-568. 11 illus. 1 table. Flight, November 5, 1936, page 466-466c. 8 illus.

Accessories

Gaskets for Aero-Engines. New jointing material, Klingerit 1000, used extensively in British aircraft engines, is said to stand the high pressures and temperatures. A few details of its composition, uniformity of thickness, and resistance properties. Aircraft Engineering, November 1936, page 316.

Injection System to Handle Fuels of All Grades at Low Pressures. Low-pressure fuel-injection system, now in production by the Marvel-Schebler Carburetor Division of the Borg-Warner Corp., is designed to handle fuels ranging from gasoline to the heavier furnace oils and has been adopted by Continental for its radial air-cooled aircraft engine. Among the advantages claimed for aircraft engines are: freedom from icing under low temperature, high-humidity conditions, positive feed under all conditions in maneuvering, and provision for altitude mixture-ratio adjustment. Long description. Automotive Industries, November 28, 1936, pages 756-757, 762. 3 illus.

Fuels and Lubricants

Knock Resistance of Light Fuels. W. Giessmann. Testing of light fuels for anti-knock qualities, possibilities of their increase, and their influence on engine operation. Ricardo method, determination of octane number, knock testing engines, measurement of knock intensity, comparison of HUC value and CFR octane number, anti-knock qualities of fuels and mixtures, designation of compression increase, the properties of fuels for airplane engines, possibilities of increasing their anti-knock qualities and their behavior at high altitudes. V. D. I., July 4, 1936, pages 833-839. 14 illus. 3 tables.

Selection of Oils for High Output Aircraft Engines. A. L. Beall. Selection by the refiner, by specification, and by full-scale engine tests. The preliminary investigation, full-scale engine test, engine inspection, oil inspection, and the rating of results are discussed. The appendices describe methods for testing lubricants in the W. A. C. oxidation cup and the W. A. C. bearing rig, and the system of rating the performance of an oil in a 50-hour endurance test determining the point score. S. A. E. Preprint for Meeting, October 15 to 17, 1936. 5 pages. 7 illus.

Welding

Aircraft Spot Welding. B. Burns. Steps in making a spot weld, roll welding, a general-purpose welder for aircraft work, the generalized relation between the various controllable factors in welding aluminum alloy 17 St, various materials commonly used in aircraft construction and pot welded on production, cost of a spot weld, characteristic features of welding machines designed expressly for aircraft work, and design trends in welding machines which must be introduced before the aircraft manufacturer can be entirely satisfied. S. A. E. Preprint for Meeting, October 15 to 17, 1936, 8 pages. 5 illus.

Records and Meetings

Altitude Record Flights. R. J. deMarolles. New regulations of the Fédération Aéronautique Internationale for accurately calculating the actual altitude reached in the course of a record attempt are explained with a review of previous methods. Instead of taking pressure alone as a criterion, the new A. A. I. method uses another definition of the ideal atmosphere characterized by simultaneous values of pressure and temperature. Special arrangements of the Potez 50 for Maryse Hilsz,

when she broke the feminine altitude record on June 23 and for G. Détré when he reached the height of 48,697.4 ft. on August 14, are described. Aircraft Engineering, November 1936, pages 299-301. 4 illus.

On a Very Good Gesellschaft. C. G. Grey. An account of the Congress at the Lilienthal Gesellschaft in October but only a brief reference to the technical papers. To be continued. Aeroplane, October 21, 1936, pages 497-500. 3 illus.

Acoustics

The National Physical Laboratory. Research carried on in the Physics Department dealing with the measurement of noise, absorption coefficients, noise abatement in automobiles and aircraft, and transmission of noise through walls and floors of buildings, some problems in optics, and research in the Electricity Department are outlined. Continuation. Engineering, November 20. 1936, pages 547-550. 3 illus.

Armament

Armament of Our Military Airplanes. Positions of fire and restrictions to sectors of fire from the different positions are discussed with reference to the Martin bi-motored bomber, Boeing 299, Breguet 460, Farman 421, and Amiot 143. Methods of firing and of sighting are taken up with reference to the Reille-Soulte or E.T.Aé. and O.P.L. methods. A photograph of the dome utilized on the British airplanes is included.

The second issue deals with the different types of airplanes which it is necessary to arm. In concluding the author compares the airplane imagined by Doulet with the present American bombers and refers to possibilities of the cannon and to the speed of projectiles. Drawings illustrate the positions of the crew in the Martin and Breguet bombers, consequences of reduction of cross section on these bombers, and the firing positions. Continuation. L'Aérophile, September and October 1936, pages 194-196 and 218-220. 7 illus.

Miscellaneous Equipment

Accessories, Components and General Work. Review of the products of over 200 firms connected with the British aircraft industry. Flight, November 12, 1936, pages 516-534. 31 illus.

The Four Winds. Apparatus said to "listen" to the beating of a pilot's heart while he is in the air and to transmit a record of it to the ground where it can be reproduced on a sound film. Design of scientific workers of the medical aviation department of the Soviet Civil Air Fleet is briefly referred to. Flight, November 5, 1936, page 461.

Materials for Aircraft. Notes on the products of the principal British suppliers of raw materials, component parts, accessories, and airport and workshop equipment for the aircraft industry. Aeroplane, November 11, 1936, pages 617-631. 19 illus.

Orifices for Flow Measurement. F. V. A. E. Engle and J. W. E. French. Discharge coefficients in the ranges of laminar flow and transition to turbulent flow and the design and installation of carrier ring orifices. Concluded. Engineering, November 6, 1936, pages 496-497. 8 illus.

Photography

Development of Indeformable Films for Photogrammetry. Causes of the deformation of films and methods for the preparation of indeformable films. Results of research undertaken at the request of the French Air Ministry. Bul. de Photogrammétrie, January-February, 1936, 10 pages. 2 illus.

Radio

Radio Bearing. H. Plendl. Explanation for the variation of the radio line of bearing at night, description of the impulse radio bearing, practical results obtained with impulse radio bearing from ground stations, and comparison of the two most important night radio bearing methods. Report of the D.V.L. and German Air Force Station. Luftfahrtforschung, October 12, 1936, pages 367-370. 9 illus.

Meteorology

Apparatus for Transmitting Cosmic-Ray Data from the Stratosphere. R. L. Doan. Instruments for measuring cohmic-ray intensity and atmospheric pressure, a method of making ionization measurements, a neon tube flasher as a signal generator, radio apparatus, batteries, and the gondola and the free balloons in which the instruments are sent aloft are described. Rev. Scientific Instruments, November 1936, pages 400-406. 6 illus.

Air Forces

AUSTRALIA

The Four Winds. A number of Bristol Blenheim high-speed medium bombers have been ordered by Australia. There will be at least one squadron of twelve machines with a reserve of the same number. Brief reference. Flight, November 12, 1936, page 486.

FINLAND

The Four Winds. Finland is to have twelve new British bombers. Brief reference. Flight, November 12, 1936, page 486.

FRANCE

The Four Winds. The French Government has earmarked £50,000,000 for expansion of the Air Force. Brief reference. Flight, November 5, 1936, page 461.

GERMANY

Black Crosses—Germany's Air Force in Action. Dornier heavy bomber, Junkers Ju. 52S with a "dustbin" turret, and a two-seater Heinkel observation airplane. Photographs only of planes in the air but said to indicate the high degree of efficiency being attained in the practice of aerial fighting and formation flying. Flight, November 5, 1936, page 466. 3 illus.

GREAT BRITAIN

On the Big Three and Lester Gardner. C. G. Grey. Formation of a British land fighting force, which would be part and parcel of the Air Force, and would be accustomed to travelling by air and descending by parachute, is suggested by Mr. Gardner in connection with his comments on his trip through Europe. He refers to the formation of such units as the most significant development in Europe. Abstracts also of papers by T. P. Wright, P. Johnson, and Lt. Commander J. Taylor presented at a dinner to Mr. Gardner. Aeroplane, November 4, 1936, pages 569-571; Flight, November 5, 1936, page 470.

The Report on the Armament Industry. Conclusions given in the Report of the British Royal Commission on the Private Manufacture of and Trading in Arms. Aeroplane, November 4, 1936, page 553; Flight, November 5, 1936, page 467.

The Whitewash Paper. White Paper entitled "Note on the Policy of His Majesty's Government in Relation to the Production of Aero Engines." A précis of the paper referring to the difference of opinion between Lord Swinton, Secretary of the State for Air, and Lord Nuffield, manufacturer of Wolseley engines, regarding the manufacture of engines for military aircraft. Aeroplane, November 4, 1936, pages 554-558; Shorter review. Flight, November 5. 1936, pages 459-460.

U. S. A.

War Machines from the States. "The Americans have some very good fighting machines but they seem to have nothing which compares with the Supermarine Spitfire or the Hawker Hurricane as single-seaters, or the Westland, or the Battle as two-seaters." Brief comment on the rumor that the British Air Ministry is going to buy American military airplanes which is considered unlikely. Aeroplane, November 4, 1936, page 551.

Miscellaneous

Factory Facilities and Federal Regulations. R. C. Gazley. Important points in welding, glueing, woodworking, cutting and forming metal members and fittings, heat treating, making fabric coverings, corrosion prevention, cleaning metal surfaces, and assembling are touched upon in a general discussion of what comprises a competent and reliable aircraft factory. Drawings of rivet imperfections and of a number of bad fittings and their correction are included. S. A. E. Preprint for Meeting, October 15 to 17, 1936, 14 pages. 5 illus.